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Utah Water Research Lab., Logan

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Separation of Algal Cells from Wastewater Lagoon Effluents

Volume II
Effect of Sand Size on the Performance of Intermittent Sand Filters

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Varying effective sand sizes, hydraulic loading rates, and application rates resulted in profound effects on effluent quality of single stage intermittent sand filtration for secondary wastewater lagoon effluents. The finer effective sand size produced an effluent that satisfied the State of Utah, Class C Regulations except for the requirements for coliform bacteria counts. The lower effective sand size produced greater influent 5-day biochemical oxygen demand and suspended solids removals. Very high coliform removal was exhibited by all prototype intermittent sand filters. The length of consecutive days of operation without plugging by the algae was increased by lowering the hydraulic loading rate.

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SEPARATION OF ALGAL CELLS FROM WASTEWATER LAGOON EFFLUENTS

Volume II: Effect of Sand Size on the Performance of Intermittent Sand Filters

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

As part of these activities, this report was prepared to make available to the sanitary engineering community a full year of operating and performance data from a field scale intermittent sand filter system employed to upgrade waste stabilization lagoon effluent. The main objective of this research was to determine the effect of sand size on filter performance.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

Varying effective sand sizes, hydraulic loading rates and application rates resulted in profound effects on effluent quality of single stage intermittent sand filtration for secondary wastewater lagoon effluents. The finer effective sand size produced an effluent that satisfied the State of Utah, Class C Regulations except for the requirements for coliform bacteria counts. The lower effective sand size produced greater influent 5-day biochemical oxygen demand and suspended solids removals. Very high coliform removal was exhibited by all prototype intermittent sand filters. The length of consecutive days of operation without plugging was increased by lowering the hydraulic loading rate. It was estimated that a single stage intermittent sand filter system with a design flow of 3785 m^3/d (1.0 MGD) and a hydraulic loading rate of 3742 $m^3/ha{\cdot}d$ (0.4 MGAD) can be constructed and operated at a cost of $70 per million gallons of filtrate (with 75 percent Federal assistance) and produce an effluent that will satisfy the State of Utah discharge requirements. Influent biochemical oxygen demand (BOD_5) concentrations and suspended solids concentrations were too low to determine whether the Federal Secondary Treatment Standards were satisfied.

This report was submitted in partial fulfillment of Contract No. 68-03-0281 by Utah State University under the sponsorship of the U.S. Environmental Protection Agency. Experimental work described and discussed herein covers the period of August 1975 to August 1976.

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SECTION 1

INTRODUCTION

NATURE OF THE PROBLEM

Waste stabilization lagoons are employed by over 4,000 communities throughout the United States for the treatment of wastewater. Apparently, 90 percent of the communities have populations of less than 5,000 people. Often these small communities are lacking in resources and competent personnel to maintain and operate sophisticated wastewater treatment facilities.

Historically, wastewater lagoons have provided small communities with simple, efficient, and economical wastewater treatment. However, as state and federal discharge requirements become more stringent, the degree of treatment achievable with a conventional lagoon system may be inadequate to satisfy these stringent discharge standards. Because a large number of small communities already employ lagoon systems and because there are significant advantages to lagoon systems, an inexpensive method of upgrading lagoon effluent is sorely needed.

Intermittent sand filtration has been shown to successfully upgrade lagoon effluent for relatively low cost (Middlebrooks et al., 1974; Marshall and Middlebrooks, 1974; Reynolds et al., 1974; Harris et al., 1975; Bishop, 1976; Hill, 1976; and Messinger, 1976). These studies have indicated that intermittent sand filter effluent quality is significantly affected by the effective size of the filter sand employed. Smaller effective size filter sands produced a higher quality effluent. However, smaller effective size filter sands and high hydraulic loading rates also significantly reduced the length of filter run. Thus, optimal intermittent sand filter operation requires balancing the effective size of the filter sand with hydraulic loading rate and length of filter run. Unfortunately, previous studies only provided a cursory evaluation of the effect of various effective size filter sands on intermittent sand filter effluent quality, hydraulic loading rate and length of filter run (Marshall and Middlebrooks, 1974).

Editorial Note: The definition of secondary treatment for federal regulation of municipal wastewater treatment plant effluents has been or is being modified. The Federal Register Vol. 41, No. 144, Monday, July 26, 1976, pp. 30786-30789, contains amendments pertaining to effluent values for pH and deletion of fecal coliform bacteria limitations from the definition of secondary treatment. The Federal Register, Vol. 42, No. 195, Friday, October 7, 1977, contains changes in the suspended solids requirements for small municipal lagoon systems serving as the sole process for secondary treatment of wastewaters.

OBJECTIVES

The general objective of the study was to evaluate the effects of various effective size filter sands and hydraulic loading rates on the effluent quality and filter run lengths of intermittent sand filters employed to upgrade facultative waste stabilization lagoon effluent.

To satisfy the above general objective, the following specific objectives were achieved on a small prototype facultative lagoon-intermittent sand filter system:

1. Evaluate the effects of various effective size filter sands on hydraulic loading rate and application rate.

2. Evaluate the effects of various effective size filter sands on effluent quality.

3. Evaluate the effects of various effective size filter sands on length of filter run.

4. Determine the cost of intermittent sand filter operation with various effective size filter sands.

5. Develop design criteria for intermittent sand filters employing various effective size sands.

SECTION 2

CONCLUSIONS

The results of this study indicate that the application rate of lagoon effluent applied to an intermittent sand filter may have a significant effect on filter effluent quality. Conclusions drawn from this study are presented below and divided according to the two application rates studied.

The following conclusions are based on data obtained with a high application rate of 0.048 m^3/sec (1.68 cfs):

1. The 0.17 mm effective size sand filters with hydraulic loading rates of 3742 m^3/ha·d (0.4 MGAD) and 1871 m^3/ha·d (0.2 MGAD) were able to satisfy the effluent biochemical oxygen demand (BOD_5) and suspended solids concentrations set forth by the State of Utah discharge requirements and the Federal Secondary Treatment Standards.

2. The 0.40 mm and 0.68 mm effective size sand with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD) were not capable of satisfying the effluent biochemical oxygen demand (BOD_5) and suspended solids concentrations established by the State of Utah, Class C Regulations. Federal Secondary Treatment Standards were met, but influent BOD_5 and SS concentrations were lower than the standards.

3. Finer effective size filter sands produced a more nitrified effluent. The 0.17 mm effective size sand filters produced a higher nitrified effluent than the other effective size sand filters.

4. Hydraulic loading rate has little effect on effluent quality of various effective size sands.

5. The 0.17 mm effective size sand filters were able to satisfy the effluent pH values established in the Federal Secondary Treatment Standards and the State of Utah discharge requirements.

6. The 0.40 mm effective size sand with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD) did not consistently satisfy the effluent pH values set forth in the Federal Secondary Treatment Standards and the State of Utah discharge requirements. The 0.40 mm filter satisfied the proposed treatment standards 50 percent of the time.

7. The 0.68 mm effective size sand with hydraulic loading rates of 9354 m^3/ha.d (1.0 MGAD) and 18,708 m^3/ha.d (2.0 MGAD) were not able to satisfy

the effluent pH values set forth in the Federal Secondary Treatment Standards and the State of Utah discharge requirements.

8. A nitrogen loss of 6 percent was generally observed in all effective size sands.

9. Filter sand size, hydraulic loading rate and application rate appeared to have negligible effects on nitrogen loss.

10. Little phosphorus removal was observed in all filter sand sizes.

11. Dissolved oxygen concentrations in the effluents from the larger effective size sands were generally higher than those observed with the fine sands (e.s. < 0.31), but none were less than 4 mg/l during the study.

12. All filter sand sizes studied met the effluent dissolved oxygen requirements established by the Federal Secondary Treatment Standards and the State of Utah discharge requirements.

13. The effluent total and fecal coliform counts do not satisfy the Federal Secondary Treatment Standards or the State of Utah discharge requirements. Disinfection of filter effluent is required.

14. Finer effective size sands produce a lower effluent total and fecal coliform concentration.

15. Total influent zooplankton removal was achieved by the 0.17 mm, 0.31 mm, 0.40 mm, and 0.68 mm effective size sands.

16. Higher influent algae removals were obtained with finer effective size sands.

17. Greater effective size sands require less time to remove the fine sands and grit accumulated from the previous days loading.

18. Hydraulic loading rate and application rate have no significant effect on the removal of fine sands and grit accumulated from the previous day's loading.

19. Cold climatic conditions found in northern Utah present no problems in operation of intermittent sand filters with various hydraulic loading rates and sand sizes.

20. High hydraulic loading rates of 28,062 $m^3/ha \cdot d$ (3.0 MGAD) resulted in short filter run lengths for the 0.40 mm and 0.68 mm effective size sands.

21. Hydraulic loading rates of 9354 $m^3/ha \cdot d$ (1.0 MGAD) and 18,708 $m^3/ha \cdot d$ (2.0 MGAD) produce satisfactory filter run lengths for the 0.40 mm and 0.68 mm effective size sands.

22. The 0.17 mm effective size sand with a hydraulic loading rate of 1871 $m^3/ha \cdot d$ (0.2 MGAD) did not plug during the study. However, the 0.17 mm filter

was scraped after 280 consecutive days of operation to remove weeds that had grown on the filter surface. The 0.17 mm filter operated 90 consecutive days without plugging following the weed removal.

23. The 0.17 mm effective size sand with a hydraulic loading rate of 1871 m^3/ha·d (0.2 MGAD) is capable of achieving filter run lengths greater than 100 consecutive days.

Lowering the application rate appears to have a profound effect on effluent quality; however, further study should be conducted with various hydraulic loading rates and effective size filter sands to fully evaluate application rates effect on effluent quality. The following conclusions are based on data obtained with a low application rate of 0.008 m^3/sec (0.29 cfs):

24. The 0.40 mm effective size sand filter with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) is capable of satisfying the effluent BOD_5 and SS concentrations established by the State of Utah, Class C Regulations.

25. Lower application rates produce a higher nitrified effluent.

26. Lower application rates appear to produce a lower effluent DO concentration.

27. Long filter run lengths may be achieved through utilizing low application rates. The 0.40 mm filter operated 40 days without cleaning or scraping during the summer months.

SECTION 3

RECOMMENDATIONS

1. The effluent quality of a 0.25 mm to 0.31 mm effective size sand filter receiving a wastewater with BOD_5 and SS concentrations in excess of the Federal Standards should be evaluated to determine whether the Federal Secondary Treatment Standards and State of Utah discharge requirements can be satisfied.

2. Higher influent biochemical oxygen demand (BOD_5) and suspended solids concentrations should be evaluated to determine the ability of 0.40 mm and 0.68 mm effective size sand filters to satisfy the Federal Secondary Treatment Standards.

3. Further study of the effects of application rates on effluent water quality is required for all effective size sands.

SECTION 4

LITERATURE REVIEW

HISTORY

Intermittent sand filtration is the intermittent application of wastewater to a natural or artificial sand bed. Initial development of intermittent sand filters is credited to Sir Edward Frankland of Britain (Emerson, 1945). In 1870, Sir Edward indicated that intermittent sand filtration was both a physical and biological process and that visually the effluent quality was hardly distinguishable from potable water. Design criteria developed by Sir Edward were employed to construct an intermittent sand filter plant at Merthyd Tydvil, Wales, in 1872 (Pincince and McKee, 1968). This plant consisted of four separate filters with a total surface area of 8 hectares (20 acres) which received raw sewage at a hydraulic loading rate of 561 $m^3/ha \cdot d$ (0.06 MGAD).

The first intermittent sand filtration system in the United States was developed by the Massachusetts State Board of Health at the Lawrence Experiment Station in 1887 (Massachusetts Board of Health, 1912). Studies conducted on the Lawrence Experiment Station intermittent sand filters indicated that (1) smaller effective size filter sands and lower hydraulic loading rates required less filter bed depth to produce a high quality effluent than coarser effective size filter sands and higher hydraulic loading rates, (2) lower hydraulic loading rates are required with smaller effective size filter sands to maintain practical filter run lengths, (3) the amount of wastewater treated by an intermittent sand filter for a given filter run length is more dependent on the concentration of the organic matter within the wastewater than on the absolute volume of wastewater, and (4) uniform distribution of wastewater over the filter surface is unnecessary.

By 1904 there were 41 intermittent sand filter plants treating wastewater from approximately 250,000 people in the United States (Fuller, 1914). Since intermittent sand filters required large land areas, as population increased their popularity diminished and they were replaced by processes requiring less land area such as trickling filters and activated sludge (ASCE-WPCF Joint Committee, 1959). However, after World War II, numerous retirement communities and tourist facilities were constructed in Florida. These relatively small installations revitalized the use of intermittent sand filters and stimulated intermittent sand filter research at the University of Florida (Emerson, 1945).

In 1947 the University of Florida conducted studies on pilot plant intermittent sand filters (Grantham et al., 1949; Furman, 1954; Calaway et al., 1952; Calaway, 1957). The filters received screened raw domestic sewage at hydraulic loading rates from 692 m^3/ha·d (0.075 MGAD) to 1637 m^3/ha·d (0.175 MGAD) and employed filter sands with effective sizes from 0.25 mm to 0.46 mm. The results of these studies indicated that (1) suspended solids performance is a function of filter sand effective size and depth of filter sand, (2) oxidation of nitrogen forms is more complete with smaller effective size filter sands, (3) organic removal efficiency increased with increasing temperatures, (4) dosing the filters twice a day permitted higher daily hydraulic loading rates, and (5) hydraulic loading rates up to 1169 m^3/ha·d (0.125 MGAD) may be employed on filter sand with an effective size of 0.25 mm and up to 1403 m^3/ha·d (0.15 MGAD) on filter sand with an effective size of 0.31 mm and 0.44 mm without significant operational difficulties.

Recently, intermittent sand filters have been employed to upgrade lagoon effluent. Several laboratory, pilot scale, and prototype studies have been conducted at Utah State University (Marshall and Middlebrooks, 1974; Reynolds et al., 1974; Harris et al., 1975; Bishop, 1976; Hill et al., 1976; Messinger, 1976). These studies have employed 0.17 mm to 0.72 mm effective size filter sands and hydraulic loading rates from 1871 m^3/ha·d (0.2 MGAD) to 14,031 m^3/ha·d (1.5 MGAD). Intermittent sand filtration of lagoon effluents has resulted in final effluent biochemical oxygen demand (BOD_5) and suspended solids (SS) concentrations of less than 10 mg/l (Reynolds et al., 1974; Harris et al., 1975).

Hill et al. (1976) conducted pilot scale studies of intermittent sand filters operated in series utilized to upgrade lagoon effluents. Series intermittent sand filter operation resulted in a high quality effluent (BOD_5 and SS < 10 mg/l) and filter run lengths in excess of 130 days. Bishop (1976) conducted pilot scale studies of intermittent sand filters receiving aerated lagoon effluents and found that intermittent sand filtration of lagoon effluents was not effective. Messinger (1976) conducted laboratory scale studies of intermittent sand filters treating anaerobic lagoon effluent and reported that intermittent sand filtration of anaerobic lagoon effluent was not effective.

PERFORMANCE

Biochemical Oxygen Demand Performance

Grantham et al. (1949) and Marshall and Middlebrooks (1974) have reported that intermittent sand filter effluent is highly oxidized and that the effluent biochemical oxygen demand (BOD) is well into the nitrogenous phase. Biochemical oxygen demand (BOD_5) performance is significantly affected by the depth of the sand filter bed as shown in Figure 1 (Grantham et al., 1949). Grantham et al. (1949) reported that the critical filter bed depth for BOD_5 removal for a 0.35 mm effective size filter sand was approximately 30 cm (12 inches). However, a practical minimum depth of filter bed for field installations is 60 cm (24 inches) (Grantham et al., 1949).

Marshall and Middlebrooks (1974) and Grantham et al. (1949) have reported that the effective size of the filter sand has a significant affect on

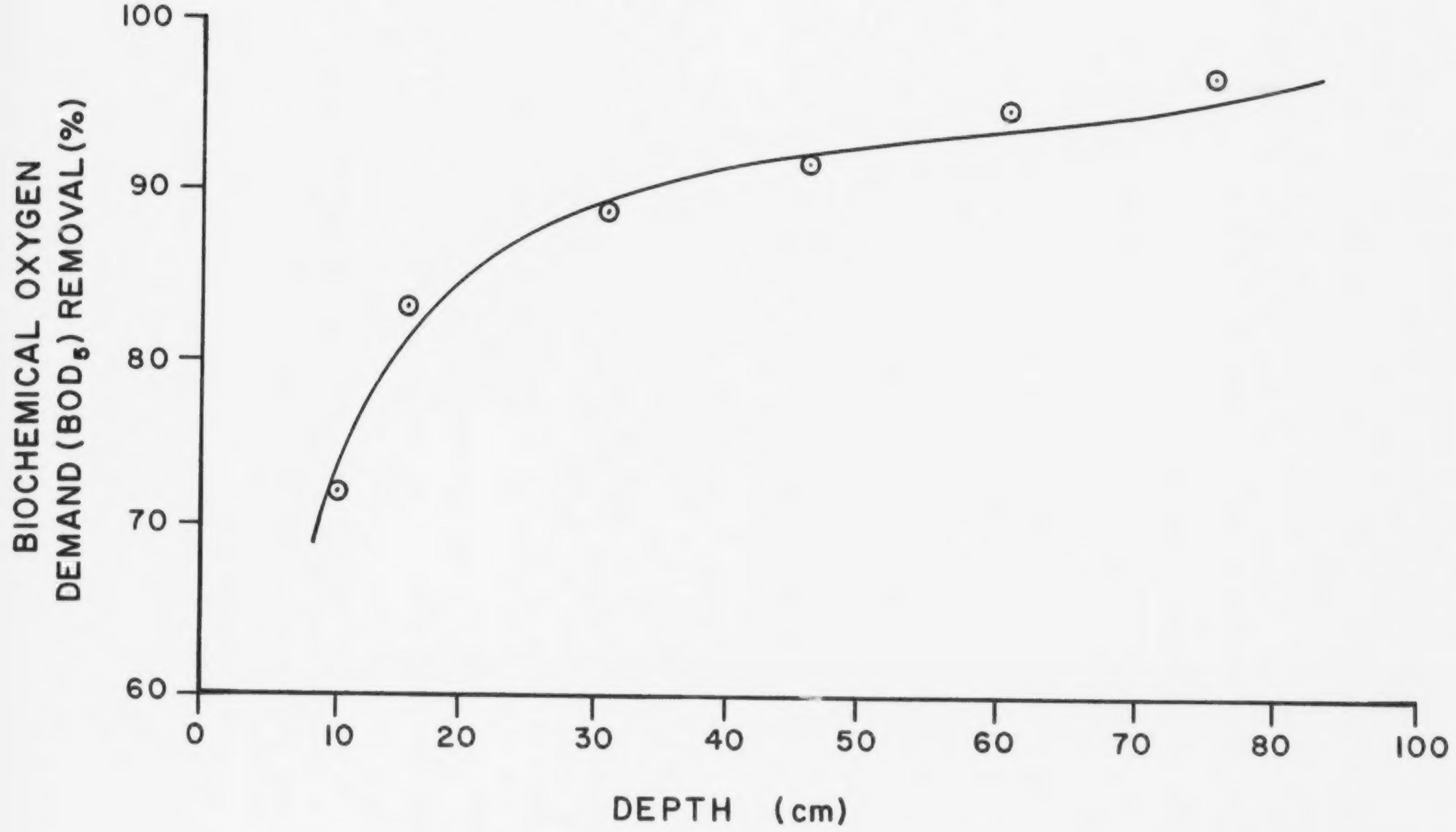


Figure 1. Percent influent biochemical oxygen demand removal of a 0.31 mm effective size sand compared with depth (Grantham et al., 1949). cm x 2.54 = inches.

intermittent sand filter BOD_5 removal. Marshall and Middlebrooks (1974) using a 0.17 mm effective size filter sand produced an average filtered effluent BOD_5 concentration of 2 mg/l with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) and an average filtered effluent BOD_5 concentration of 4 mg/l with a hydraulic loading rate of 7483 m^3/ha·d (0.8 MGAD). However, with a 0.72 mm effective size filter sand the filtered effluent BOD_5 concentration increased to 5 mg/l with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) and 6 mg/l with a hydraulic loading rate of 5612 m^3/ha·d (0.6 MGAD).

Suspended Solids Performance

Studies performed at the University of Florida (Furman, 1954) reported suspended solids removals ranging from 89 percent to 96 percent with influent suspended solids concentrations ranging from 90 mg/l to 130 mg/l. Salvato (1972) states that intermittent sand filters if operated properly can attain 90 percent to 98 percent influent suspended solids removal.

Recent studies performed at Utah State University reported effluent suspended solids concentrations were near zero immediately before an intermittent sand filter plugged. As the intermittent sand filter approaches failure, the infiltration rate decreases, increasing the influent suspended solids removal (Marshall and Middlebrooks, 1974). Laboratory studies by Marshall and Middlebrooks (1974) showed that hydraulic loading rate has little effect on suspended solids removal efficiency, and that finer effective size filter sands produce higher suspended solids removals.

Hill et al. (1976) reported 75 percent removal of the influent suspended solids with a series intermittent sand filter system of 0.72 mm, 0.40 mm, and 0.17 mm effective size filter sands. The 0.72 mm effective size sand filter removed the major portion of the influent suspended solids. Harris et al. (1975) showed that the length of filter run is related to the influent suspended solids concentration and the hydraulic loading rate. Harris et al. (1975) also concluded that an effluent suspended solids concentration of less than 10 mg/l can be attained with intermittent sand filters used to upgrade lagoon effluent.

Phosphorus Removal Efficiency

Significant amounts of phosphorus are not removed by intermittent sand filtration. Marshall and Middlebrooks (1974) have shown that initially phosphorus will be removed by adsorption to the sand particles. However, once the ion exchange sites within the sand filter bed have saturated, significant phosphorus removal does not occur.

A study conducted at the Whitby Experimental Station, Ontario, Canada, resulted in considerable phosphorus reduction with intermittent sand filters by mixing a "Red Mud" into the upper 20 cm (8 inches) of the sand filter bed (Chowdry, 1972, 1973). The "Red Mud," which was composed of 16.7 percent SiO_2, 2.5 percent CaO, 22.7 percent Na_2O, 22.7 percent Al_2O_3 and 25.3 percent Fe_2O_3, increased the number of ion exchange sites available for phosphorus adsorption. Once the adsorption sites became saturated, significant phosphorus removal ceased.

Nitrogen Removal Performance

Oxidation of ammonia to nitrate within the intermittent sand filter bed has been reported by Furman et al. (1955) and Grantham et al. (1949). Grantham et al. (1949) reported that oxidation of ammonia to nitrate increased as the depth of filter bed increased and also as the effective size of the filter sand became smaller. With an effective size filter sand of 0.31 mm and a hydraulic loading rate of 115 m^3/ha·d (0.075 MGAD), Grantham et al. (1949) observed that 98 percent of the influent ammonia was oxidized to nitrate. Grantham et al. (1949) also reported better nitrification occurred when two equal doses of wastewater per day were applied to the filters.

Pincince and McKee (1968) found that the aerobic condition of the sand filter bed has a significant affect on the oxidation of ammonia to nitrate in intermittent sand filters. Their hypothesis is illustrated in Figure 2. Pincince and McKee (1968) postulated that the nitrate concentration within the sand filter bed would be constant while water was ponded on the sand filter surface (i.e., t_0 in Figure 2). Once the water had infiltrated into the sand filter bed, leaving the sand filter surface exposed to the atmosphere, oxygen (air) would move into the sand filter bed and nitrification would commence (i.e., t_1 to t_3 in Figure 2). As the oxygen penetrates deeper into the sand filter bed, nitrification at deeper depths will occur (i.e., t_4 to t_7 in Figure 2).

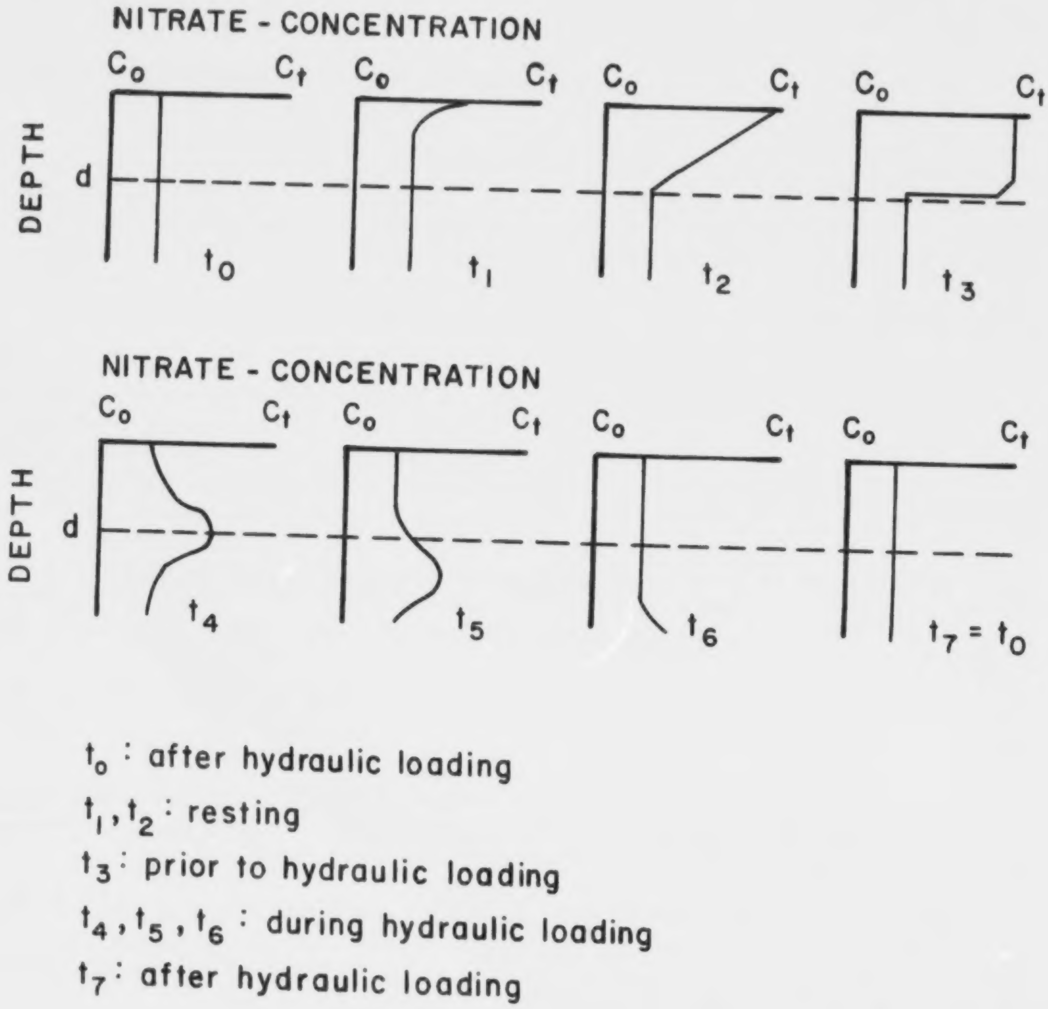
CLIMATIC STUDIES AND EFFECTS

Many ideas have been proposed to overcome the effects of harsh winter climatic conditions upon intermittent sand filters. Techniques of winter maintenance and operation differ among designers.

Metcalf and Eddy (1935) reported that best filtration results during the winter are obtained by leaving the intermittent sand filter beds flat. The chief reasons are the expense of furrowing the beds and the greater difficulty in removing the accumulated solid matter from the furrows.

Frost (Fuller, 1914) considered the application of large doses to be one of the vital points in the maintenance of sewage filters during the winter. Frost did not attempt to keep an area of filtering surface open during the winter. While operating in this mode, Frost also planted corn on the beds. When the stalks were cut the mounds allowed the ice formations to rest upon them, keeping the filtering material open.

Bolling (1907) furrowed the filter bed with furrows 91.4 cm (3 feet) apart and 30.5 cm (12 inches) deep. The ice rested upon the tops of the ridges. Allardice (Fuller, 1914) reported that the Clinton, Massachusetts, plant was operated in much the same manner as Bolling used at Brockton, Massachusetts. However, only 20 percent of the beds were furrowed during the winter months. The City of Brockton had experienced little difficulty in this technique with hydraulic loading rates exceeding 4677 m^3/ha·d (0.5 MGAD) upon the furrowed beds (Daniels, 1945).


NITRATE - CONCENTRATION
C₀
Cₜ
DEPTH
d
t₀
t₁
t₂
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NITRATE - CONCENTRATION
C₀
Cₜ
DEPTH
d
t₄
t₅
t₆
t₇ = t₀
t₀ : after hydraulic loading
t₁ , t₂ : resting
t₃ : prior to hydraulic loading
t₄ , t₅ , t₆ : during hydraulic loading
t₇ : after hydraulic loading

Figure 2. Hypothesized variation of nitrate concentration in sand filters (Pincince and McKee, 1968).

Reynolds et al. (1974) reported that winter operation of filters under fairly harsh climatic conditions did not create any serious operational problems. Reynolds et al. (1974) performed the experiment under four modes of operation which are shown in Table 1.

TABLE 1. LENGTH OF FILTER RUNS DURING A WINTER EXPERIMENTAL PERIOD AT UTAH STATE UNIVERSITY (REYNOLDS ET AL., 1974)

Mode of Operation	Filter Number	Hydraulic Loading Rate (MGAD)	Length of Filter Run (Days)
Control	6	0.2	189
Furrowed	1	0.4	131
Flooded	2	0.4	80
Staked	4	0.4	92

FILTERING MECHANISMS

The development and improvement of sand filtration of wastewater progressed without the full understanding of the mechanisms of filtration (Camp, 1964). Tchobanoglous (1970) reported nine mechanisms involved in rapid sand filtration which may be applied to intermittent sand filters (Table 2). Removal mechanisms 1 through 4 are related to the physical characteristics of a filter sand. Mechanisms 5 through 8 are related to the chemical properties of the filtration process, and the final mechanism refers to the biological activity in the filter.

Sand filter purification is not solely a mechanical mechanism. The high BOD_5 performance results achieved by intermittent sand filtration are higher than would be expected by mechanical properties alone. Large numbers of bacteria, protozoa and many multicellular organisms are present in active efficient filters. Calaway (1957) states that biological oxidation is the most important removal mechanism of intermittent sand filtration. Six groups of bacteria (Calaway, 1957) are the primary agents in the oxidation of organic substances; however, bacterial growth would contribute to plugging if the bacteria were not consumed by protozoa and metozoa. Calaway (1957) reported the oligochaet worm to be the most important member of the metozoa group, which feeds on the slimes and sludges of the filter bed and thus keeping the bed open and accessible to oxygen.

The number of bacteria reported decreased with depth and increased with an increase in dosings. The presence of Flavobacterium was more prominent with high hydraulic loading rates. Bacillus was reported in greater numbers with lower hydraulic loading rates (Calaway, 1957).

CLOGGING MECHANISMS

Using hydraulic conductivity as a measure, Jones and Taylor (1965) working with slow sand filters receiving septic tank effluent reported that the initial soil clogging zone is the region at the sand gravel interface and occurs 3 to 10 times faster under an anaerobic environment than under an

TABLE 2. FILTRATION PROCESS VARIABLES AND PARTICLE REMOVAL MECHANISMS AS STATED BY TCHOBANOGLOUS (1970)

Process Variables	Removal Mechanisms
1. Filter media grain size, shape, and density	1. Straining:
2. Filter media porosity	a. Mechanical
3. Media headloss characteristics	b. Chance contact
4. Filter bed depth	2. Sedimentation
5. Filtration rate	3. Inertial impaction
6. Allowable headloss	4. Interception
7. Effluent characteristics	5. Chemical adsorption:
8. Chemical treatment	a. Bonding
9. Floc strength	b. Chemical interaction
10. Filter bed charge	6. Physical adsorption:
11. Fluid characteristics	a. Electrostatic forces
	b. Electrokinetic forces
	c. Van der Waals forces
	7. Adhesion and adhesion forces
	8. Coagulation-flocculation
	9. Biological growth

aerobic condition. Three distinct phases of clogging were noted under aerobic conditions. The first phase was a sudden drop of performance (hydraulic conductivity declines to near 25 percent of its initial value). During the second phase, performance fluctuates slightly and the third phase represents complete filter plugging. However, deVries (1972) also working with hydraulic conductivity, stated that clogging occurred on the surface of the sand filter.

Mitchell and Nevo (1964) reported that the plugging condition is caused by the accumulation of polysaccharides both with and without glueuronic acid residues. Their studies also indicated that ferrous sulfide accumulation had little effect on water percolation. Similar experimentation by Avnimelch and Nevo (1964) reported that clogging was more highly correlated with polyurcnide concentrations than with polysaccharide concentrations. Harris et al. (1975) indicated that heavy algal growth which caused pH to exceed a value of 10 produces calcium carbonate precipitation. This calcium carbonate precipitate forms a "plaster like" film on the filter surface and thus causes the filter to plug.

DESIGN AND OPERATION

Many factors govern the design of intermittent sand filters. Intermittent sand filters have been used as a primary, secondary and recently as a tertiary means of treatment. The land area required, coupled with the extensive manual labor for maintenance of the filters probably limits the use of intermittent sand filters to small communities.

The preliminary treatment, an essential part of the process, may consist of primary settling treatment only, or more complete treatment may be provided before the wastewater is applied to the intermittent sand filter. Sand filtration following biological treatment will produce an effluent hardly distinguishable in appearance from drinking water; therefore, in many cases subsequent treatment is not needed unless disinfection is required (Babbitt and Baumann, 1958).

Construction

A flexible operation will have a minimum of three intermittent sand filters and preferably four. If multiple filters are used one can be in use, one drying, another being cleaned and the fourth being a spare for adverse flow conditions. Other than the minimum requirement, the quantity of intermittent sand filters needed is dependent upon the total average daily flow and the maximum number of doses to be applied daily.

The size, shape and grouping of intermittent sand filters are dictated by topography, means of distributing the influent over the beds and collecting the effluent in underdrains, as well as economics. Intermittent sand filters having areas of approximately one acre have proved most desirable (Metcalf and Eddy, 1935; Steel, 1960). The majority of intermittent sand filters constructed are rectangular in shape with the underdrainage system and means for distribution of sewage having the greatest influence in determining the shape. A design using long beds is discouraged as the distribution of sewage is not uniform unless troughs are used. Troughs interfere with the maintenance of the sand filters.

The floor of an intermittent sand filter is pitched to a slight grade for collecting the effluent into open joint or perforated tile underdrains. The underdrains are usually laid in trenches below the bottom layer of the sand so as to make the entire depth of sand effective for filtration and keep the drains well below the sand surface. The drains are usually constructed to have a free outlet (Babbitt and Baumann, 1958). The main underdrain is usually 15 cm (6 inches) or 20 cm (8 inches) in diameter and may be laid down the center of the filter, or along the side of the filter. Laterals feeding into the main have a minimum diameter of 10 cm (4 inches) and are spaced up to 9.1 m (30 feet) with 4.6 m (15 feet) or less a more common value (ASCE-WPCF Joint Committee, 1959). The underdrains should be laid on a slope sufficient to give a velocity of 0.91 m/sec (3 fps) to 1.2 m/sec (4 fps) when flowing full. Clay tile and PVC drain pipe have been used successfully. The use of concrete pipe is discouraged due to its inability to resist deterioration by acids biologically formed in the beds.

Embankments for intermittent sand filters are constructed in the same manner as for lagoons (Missouri Basin Engineering Health Council, 1971). Embankment slopes range from 2:1 to 6:1 of compacted soil. The use of soil embankments is the most economical construction method, but because of weed growth and erosion, soil embankments require the most maintenance. Embankments must be mowed continually to keep the vegetation from encroaching on the sand filters (Metcalf and Eddy, 1935). Rip rap is often placed on the embankment to prevent or curtail weed growth and erosion. Reinforced rubber lining has been successfully used in small filter systems.

Filter Media

Filter media selection is governed by the availability of sand and by the quality of effluent desired. The bottom layer is usually washed gravel, broken stone or blast furnace slag placed in three layers of varying sizes. A 12.5 cm (5 inch) layer of 3.8 cm (1.5 inch) to 5.1 cm (2 inch) aggregate is placed about the underdrain. A 7.6 cm (3 inch) layer of 1.9 cm (0.75 inch) to 2.5 cm (1.0 inch) aggregate is placed above the coarse aggregate. The next layer consists of 1.3 cm (0.5 inch) to 0.6 cm (0.25 inch) diameter gravel at a depth of approximately 10.2 cm (4 inches), giving a total depth of approximately 30.5 cm (12 inches) for the support layer.

The Ten States Authority (Babbitt and Baumann, 1958) recommends an effective size sand between 0.36 mm and 0.60 mm with a uniformity coefficient not greater than 3.5. The Committee on Filtering Materials of the American Society of Civil Engineers (Babbitt and Baumann, 1958) recommend that the sand not exceed 0.2 mm to 0.5 mm effective size and the uniformity coefficient be less than 5.0. However, other studies have shown that a uniformity coefficient of 10 has almost identical hydraulic characteristics as a filter sand with a uniformity coefficient of 1.0, as long as the effective size remains equal (Salvato, 1954). Harris et al. (1975) and Reynolds et al. (1974) employed a filter sand with an effective size of 0.17 mm and a uniformity coefficient of 9.74 to upgrade lagoon effluents. The sand should be free from roots and cementing materials, relatively insoluble and devoid of significant amounts of organic matter and clay. Siliceous sands that are rounded or oval are preferred over sharp, calcareous or argillaceous material (Babbitt and Baumann, 1958).

Depth of the filter media has a pronounced effect upon the quality of effluent; however, beyond the "critical depth" of the filter, effluent quality increases at a slow rate. An investigation by Furman et al. (1955) illustrated the effects of depth versus effluent quality and is shown in Figure 1. Filters constructed with depths of 76.2 cm (30 inch) to 101.6 cm (40 inch) insure high performance and allow needed maintenance without replacing or adding additional sand for several years. Shallow beds require that underdrains be spaced at lower intervals (Furman et al., 1955).

Operation and Maintenance

Filter hydraulic loading rates have been found to have little effect on effluent quality; however, the hydraulic loading rate has a profound effect upon the length of filter cycle. Hydraulic loading rates exceeding 9354 m^3/ha·d (1.0 MGAD) have produced cycles of less than 20 days, using secondary lagoon effluent (Harris et al., 1975). Hydraulic loading rates of 1871 m^3/ha·d (0.2 MGAD) and 3742 m^3/ha·d (0.4 MGAD) under similar conditions have doubled the filter cycle (Harris et al., 1975). Hydraulic loading rates often employed with intermittent sand filtration are illustrated in Table 3 (Metcalf and Eddy, 1935).

TABLE 3. RECOMMENDED HYDRAULIC LOADING RATES FOR A 0.2 MM TO 0.35 MM EFFECTIVE SIZE SAND FILTER (METCALF AND EDDY, 1935)

Type of Filter	Hydraulic Loading Rate (m^3/ha·d)	Persons Per Acre
Primary Treatment	187 - 701	400 - 1000
Secondary Treatment	468 - 1169	500 - 1500
Tertiary Treatment	935 - 7483	1000 - 10000

Controlled distribution of the wastewater is necessary to prevent erosion and permit uniform application of sewage upon the filter (Metcalf and Eddy, 1935; Holmes, 1945; ASCE-WPCF Joint Committee, 1959). Control of distribution may be accomplished through several methods such as:

1. Troughs running the full length of the beds
2. Radiating or arterial troughs
3. Quarter point distribution
4. Corner point distribution

Distribution points should be spaced not more than 9.1 m (30 feet) to 18.2 m (60 feet) apart with a concrete slab not over 0.61 m (24 inches) in diameter placed at outlets to prevent erosion.

Multiple dosing of filters has been found to produce a higher quality effluent (Furman et al., 1955; Imhoff et al., 1973). However, the appropriate size and frequency of the dose depend largely on the effective size of the filter sand, condition of the filter bed and the character of the wastewater applied. A dose should reach a maximum head of 10.2 cm (4 inch) and disappear within 20 minutes to maintain proper aeration and peak performance of the intermittent sand filter (Babbitt and Baumann, 1958). Reynolds et al. (1974) recommended that hydraulic loading of intermittent sand filters be performed during the hours of darkness to limit algae growth in the influent on the filter bed.

Once the filter has reached a condition where the influent from the previous day's loading remains over 100 percent of the surface area, the filter is considered plugged. Several methods of rejuvenating a clogged intermittent sand filter have been tried. Story (1909) used two methods to rejuvenate clogged slow sand filters. Raking the surface proved satisfactory but was not performed too frequently because the mixing of deposited fine materials became mixed with the sand and decreased filter performance. Removal of the thin surface coat proved to be the best means of rejuvenation, but involved a great deal more effort. Harris et al. (1975), Babbitt and Baumann (1958), Metcalf and Eddy (1935), and Daniels (1945) all stress that removal of the clogged surface area is essential in reaching an optimum length of filter cycle.

Furman et al. (1955) attempted to rejuvenate a filter by allowing the bed to rest for 8 to 10 days, but this proved ineffective, with filter runs very seldom exceeding 7 days after resting. However, studies conducted by Schwartz et al. (1967) indicate that the filter may be rejuvenated if allowed to rest after clogging (see Table 4).

Possibly one of the major disadvantages with an intermittent sand filter system is the replacement of spent filter sand (Mitchell, 1921). Mechanical washers have been used in the eastern United States with success (Gaub, 1915; Karalekas, 1952). The basic sand washer consists of hydraulic ejectors and rakes working simultaneously. A suction is placed above the system to remove the fines and grit. The effectiveness of six methods of rejuvenating a filter are summarized in Table 5 (Gaub, 1915). The Brooklyn and Nichols methods are mechanical washers that wash the in-place filter sand. The piling method involves scraping the sand filter and piling the spent filter sand on the filter bed to be removed once yearly. The spading method merely required the filter surface to be broken and overturned.

Elliott et al. (1976) reported on a new irrigation technique that is capable of rejuvenating the spent filter sand for minimum cost. The irrigation technique consists of depositing the spent filter sand on a sludge drying bed and irrigating the bed with 5 cm (2 inch) of potable water weekly, for 6 weeks.

ECONOMIC ANALYSIS

Engineering News Record (1976) Cost Indices were used to update reported costs to 1976 values. Costs reported in the literature are listed and then followed by the updated 1976 value in parenthesis.

Construction costs of intermittent sand filters are largely dependent upon the availability of sands with the proper effective size and the value of land. Story (1909) reported an entire construction cost of $50,724 ($1,214,840) for 1.6 ha (4 acres) of slow sand filters. Construction costs in 1903 of $1320 per ha ($33,902) or $3260 per acre ($84,760) of intermittent sand filter in Massachusetts was reported by Fuller (1914). Metcalf and Eddy (1935) reported a construction cost of $3,540 per ha ($53,100) or $8,850 per acre ($132,750) in 1924. Hill et al. (1976) reported construction costs of $2227 per ha to $2551 per ha ($55,000 per acre to $63,000 per acre) for two intermittent sand filters in series and built in existing cells of a lagoon system. A 1136 m^3/ha·d (0.3 MGAD) lagoon intermittent sand filter system in Huntington, Utah, was completed in 1976 at a total cost of $600,858. This included the cost of the collection system, facultative lagoons and intermittent sand filters (Valley Engineering, 1977).

Maintenance and operating costs of intermittent sand filters will vary according to design flow, design flow rate and available labor. In 1903 the Massachusetts Board of Health reported operating costs of $2.05 ($53.20) per 1000 m^3 or $7.75 ($201.50) per million gallons of filtered effluent. Seven years later Powell (1911) reported a slow sand filter operating cost of $0.72 ($17.07) per 1000 m^3 or $2.74 ($64.66) per million gallons of filtrate in Baltimore, Maryland.

TABLE 4. DEGREE OF REJUVENATION OF A PLUGGED INTERMITTENT SAND FILTER AT VARIOUS PERIODS OF REST (SCHWARTZ ET AL., 1967)

Resting Duration (Days)	Percent of Original Hydraulic Acceptance Rate Recovered
8	34
10	60
25	136
101	104

TABLE 5. COMPARISON OF FILTER RUN PERFORMANCES WITH VARIOUS METHODS OF REJUVENATING A PLUGGED INTERMITTENT SAND FILTER (GAUB, 1915)

Method	Yield ($m^3 \times 10^{-5}$)			Days Run		
	Max.	Min.	Ave.	Max.	Min.	Ave.
Brooklyn	2.5	0.2	0.7	49	6	14
Removal	14.3	0.4	2.8	105	4	27
Nichols	21.5	1.1	5.7	148	11	45
Rake No. 1	10.6	0.1	3.2	75	2	24
Rake No. 2	4.5	0.4	2.0	31	6	15
Rake No. 3	2.8	0.4	1.6	24	5	14
Piling	6.3	0.1	1.3	19	2	18
Spading	3.4	0.4	1.9	22	4	15

Million Gallons x 3785 = m^3

Recent studies by Marshall and Middlebrooks (1974), Harris et al. (1975), Bishop (1976), and Messinger (1976) have estimated total cost of $3.96 to $17.16 per 1000 m^3 ($15 to $65 per million gallons) of filtrate with 75 percent Federal assistance. Hill et al. (1976) estimated the total cost using intermittent sand filters in series to be $10.30 to $23.50 per 1000 m^3 ($39 to $89 per million gallons) of filtered effluent.

Comparing the cost of intermittent sand filters with other processes to polish wastewater lagoon effluents, Middlebrooks et al. (1974) found the intermittent sand filter to be very competitive. Though the cost indices have increased substantially during recent years, it is likely that the cost of intermittent sand filters has increased proportionally with other treatment processes, allowing the intermittent sand filter to remain a favorable method of upgrading lagoon effluents.

SECTION 5

METHOD AND PROCEDURES

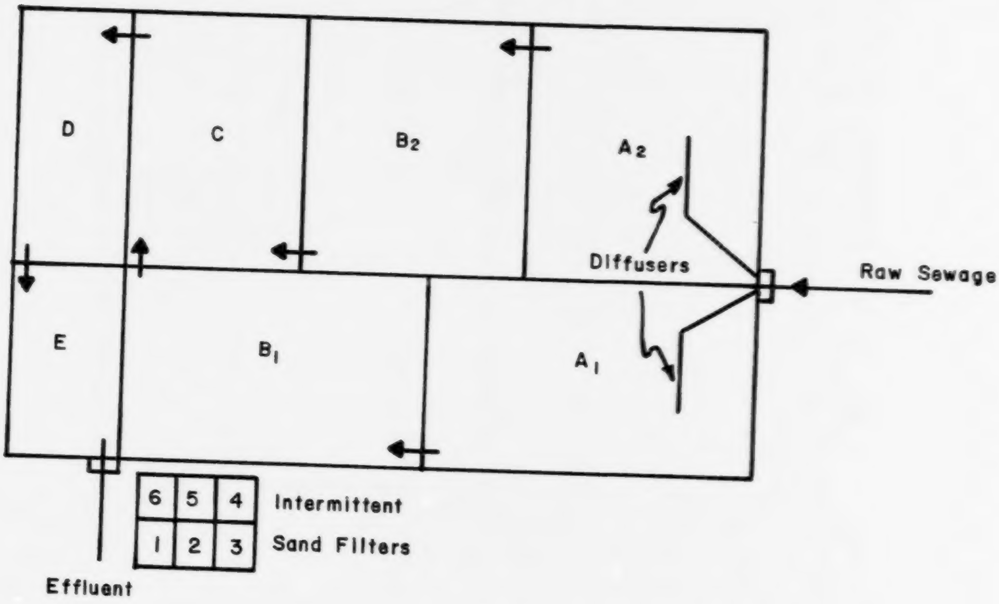
EXPERIMENTAL SETTING

The intermittent sand filtration study was performed at the Logan Municipal Sewage Lagoons, Logan, Utah. The lagoon system is described in Figure 3 and Table 5. Six prototype single stage intermittent sand filters, 7.6 m (25 feet) by 11.0 m (36 feet) (83.6 m^2 [900 sq. feet]) were utilized. This was the same facility employed by Harris et al. (1975). A schematic of the facility is shown in Figure 4. Construction of the facility was performed by a local firm, using materials that were readily available with the exception of the 0.31 mm, 0.40 mm, and 0.68 mm effective size filter sands. These sands were prepared by sieving a local sand to achieve the desired effective size. A cross section of a typical filter is shown in Figure 5. The soil embankment was constructed of bank run granular fill material. To prevent infiltration and exfiltration, the filters were lined with a 10 mil vinyl material. The drainage system consisted of 10.2 cm (4 inches) perforated corrugated PVC pipe placed at a slope of 0.025. The filter bed consisted of 10.2 cm (4 inches) of 3.8 cm (1 1/2 inches) maximum diameter rock, followed by 10.2 cm (4 inches) of 1.9 cm (3/4 inch) maximum diameter rock. The final 10.2 cm (4 inches) layer supporting the filter sand was 0.6 cm (1/4 inch) maximum diameter rock. The filter sand is approximately 91.4 cm (36 inches) deep. Table 7 indicates the effective size of each sand employed in the experiment and a sieve analysis of each filter sand is shown in Table 8.

The intermittent sand filters were loaded once daily during the late morning hours with secondary effluent from the Logan Municipal Sewage Lagoon system. Hydraulic loading rates and application rates utilized by the six prototype single stage intermittent sand filters are shown in Table 7.

An intermittent sand filter is considered plugged if the sand filter bed (100 percent of the surface area) is covered with influent 24 hours after a loading. Once an intermittent sand filter became inoperative, it was necessary to remove the "schumtzdecke" before proper operation can resume. During the experiment removal of the plugged filter surface sand was accomplished by scraping off the top 10 cm (4 inches) of the sand from the surface of the filter. This procedure fully restored the intermittent sand filter to normal operation. Other methods of rejuvenating a plugged sand filter that were tried during the experiment, but proved unsuccessful were, resting the plugged filter and burning the filter surface. The

Cell	Water Surface Area (Hectares)	Effective Vol. m^3
A_1	38.5	704,000
A_2	38.4	703,000
A_2	28.7	586,000
B_2	29.3	598,000
C	26.1	580,000
D	15.9	384,000
E	11.5	297,000
Total	188.4	852,000


D
C
B2
A2
Diffusers
Raw Sewage
E
B1
A1
6
5
4
1
2
3
Intermittent
Sand Filters
Effluent

Flow Diagram of

LOGAN, UTAH LAGOON

Figure 3. The location of the intermittent sand filters with respect to the City of Logan's lagoon system.

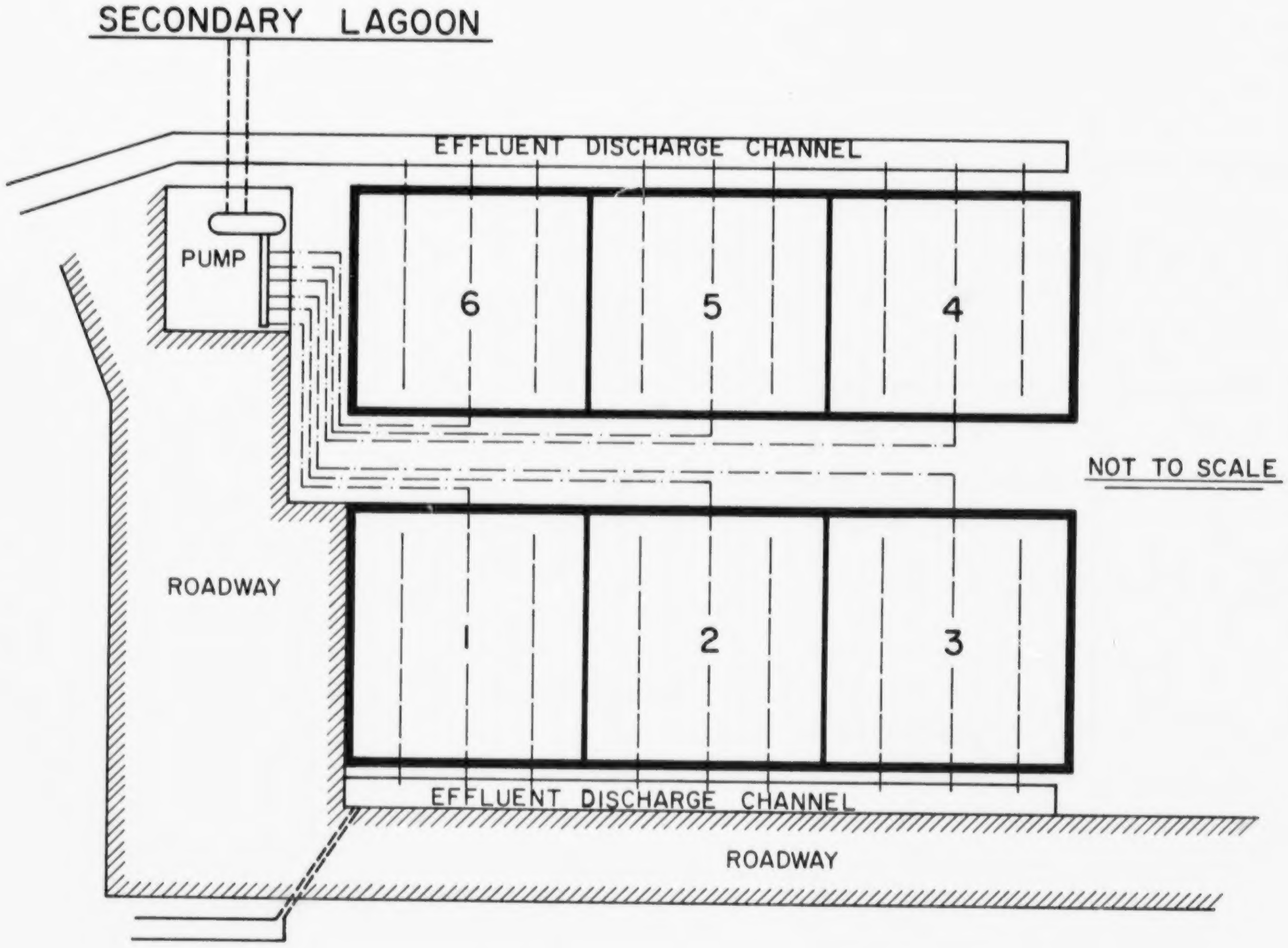

SECONDARY LAGOON
EFFLUENT DISCHARGE CHANNEL
PUMP
6
5
4
NOT TO SCALE
ROADWAY
1
2
3
EFFLUENT DISCHARGE CHANNEL
ROADWAY

Figure 4. A plan view of the six single stage prototype intermittent sand filters utilized in the experiment.

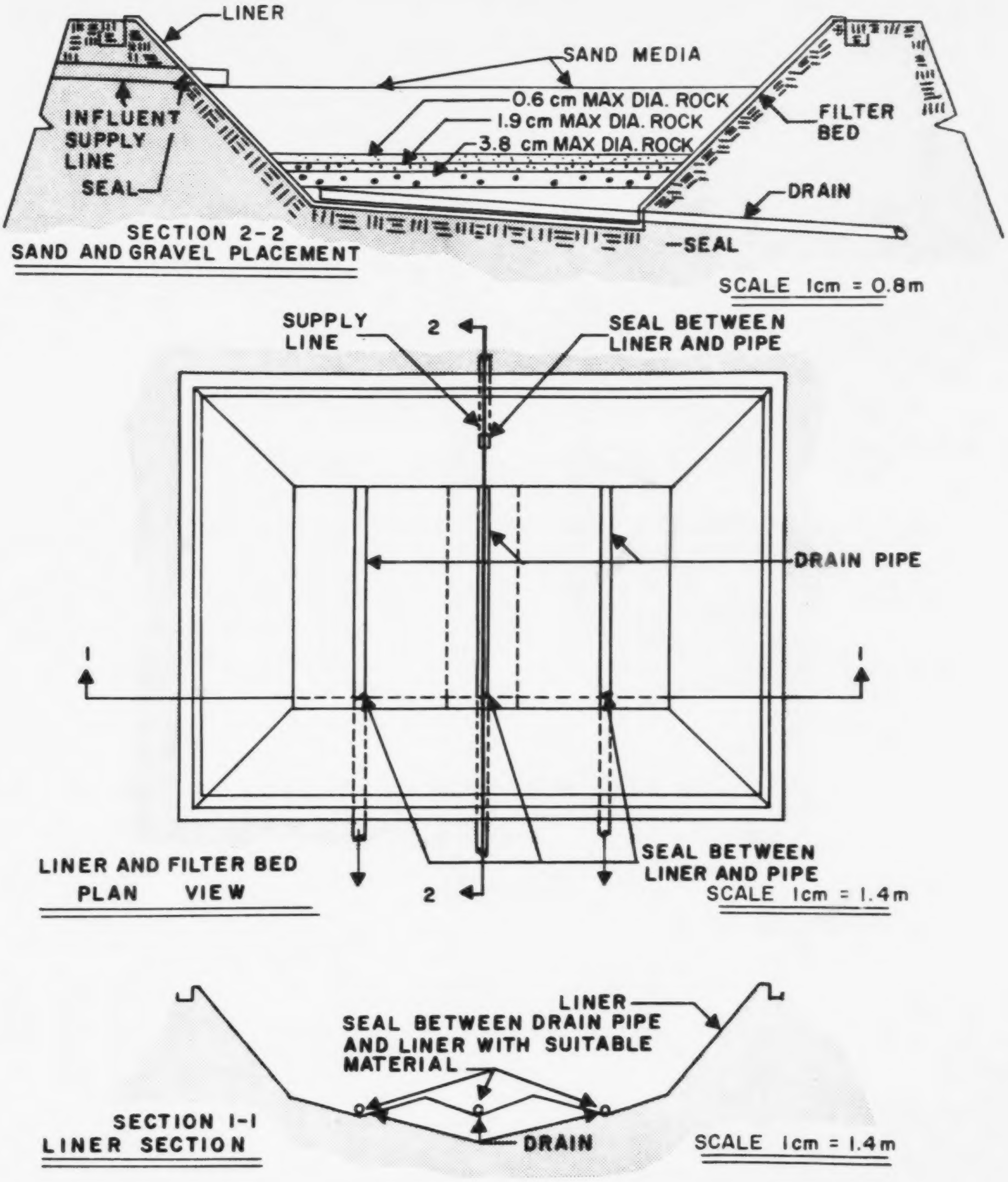

LINER
SAND MEDIA
0.6 cm MAX DIA. ROCK
1.9 cm MAX DIA. ROCK
3.8 cm MAX DIA. ROCK
INFLUENT SUPPLY LINE
SEAL
FILTER BED
DRAIN
SEAL
SECTION 2-2
SAND AND GRAVEL PLACEMENT
SCALE 1cm = 0.8m
SUPPLY LINE
2
SEAL BETWEEN LINER AND PIPE
DRAIN PIPE
1
1
SEAL BETWEEN LINER AND PIPE
LINER AND FILTER BED
PLAN VIEW
2
SCALE 1cm = 1.4m
LINER
SEAL BETWEEN DRAIN PIPE AND LINER WITH SUITABLE MATERIAL
SECTION 1-1
LINER SECTION
DRAIN
SCALE 1cm = 1.4m

Figure 5. A typical intermittent sand filter design. (1 in = 2.5 cm and 1 ft = 0.348 meters)

TABLE 6. DESCRIPTION OF LOGAN MUNICIPAL SEWAGE LAGOON SYSTEM

Cell	Water Surface Area (Hectares)	Effective Vol. m^3	Normal Oeprating Depth (ft)
A_1	38.5	704,000	1.8
A_2	38.4	703,000	1.8
B_1	28.7	586,000	2.0
B_2	29.3	598,000	2.0
C	26.1	580,000	2.2
D	15.9	384,000	2.4
E	11.5	297,000	2.6
Total	188.4	852,000	

Meters x 3.281 = feet; Hectares x 2.471 = acres; Meters^3 x 35.31 = feet^3

TABLE 7. EFFECTIVE SIZE OF SANDS, HYDRAULIC LOADING RATES, AND APPLICATION RATES UTILIZED IN THE STUDY

Filter Number	Effective Size of Filter Sand (mm)	Hydraulic Loading Rate ($m^3/ha{\cdot}d$)	Application Rate (m^3/sec)	Period of Operation
1	0.17	3,742	0.048	Aug. 15, 1975 to Aug. 25, 1976
6	0.17	1,871	0.048	Aug. 15, 1975 to Aug. 25, 1976
3	0.31	9,354	0.048	June 28, 1976 to Aug. 11, 1976
	0.31	9,354	0.008	Aug. 12, 1976 to Aug. 25, 1976
2	0.40	14,031	0.048	Aug. 15, 1975 to Aug. 20, 1975
	0.40	9,354	0.048	Aug. 27, 1975 to May 9, 1976
	0.40	9,354	0.008	May 10, 1976 to Aug. 25, 1976
5	0.40	28,062	0.048	Aug. 15, 1975 to Aug. 17, 1975
	0.40	18,708	0.048	Aug. 27, 1975 to July 8, 1976
	0.40	9,354	0.008	July 19, 1976 to Aug. 25, 1976
3	0.68	14,031	0.048	Aug. 24, 1975 to Oct. 9, 1975
	0.68	9,354	0.048	Oct. 31, 1975 to June 10, 1976
4	0.68	28,062	0.048	Aug. 24, 1975 to Sept. 4, 1975
	0.68	18,708	0.048	Sept.18, 1975 to May 14, 1976
	0.68	9,354	0.008	June 2, 1976 to Aug. 25, 1976

technique of restoring a plugged filter is discussed in detail in the "Length of Filter Operations" section.

SAMPLING AND ANALYSIS

Sampling was initially conducted twice weekly (August 15, 1975 to September 30, 1975). However, it was later decided to extend the entire study an additional two months, therefore, samples were collected once a week from October 1, 1975 to August 25, 1976. Grab samples of filter influent and effluent were collected and analyzed for suspended solids, 5-day biochemical oxygen demand, chemical oxygen demand, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, total Kjeldahl nitrogen, total phosphorus, ortho-phosphate, alkalinity, temperature, and the dissolved oxgen concentration of both the filter influent and effluent were measured in-situ at the time the weekly grab samples were collected. Table 8 summarizes the procedure used in analyzing the samples. Analysis of the samples were performed at the Utah Water Research Laboratory. The efflent samples from the 0.17 mm effective size sand filters (Filters No. 1 and 6) were collected two hours after the filters were loaded. Samples from the 0.31 mm, 0.40 mm, and 0.68 mm effective size sand filters (Filters No. 2, 3, 4, and 5) were collected 30 minutes after loading the filter. The time lapse before sampling was necessary in order to eliminate contamination from the fine sands and grit being washed out from the previous day's loading. The "wash-out" effect is discussed further in the section entitled "Variations in Suspended Solids Concentrations with Time."

TABLE 8. INITIAL SIEVE ANALYSIS OF THE VARIOUS FILTER SANDS USED

Sieve Size Number	Opening (mm)	Percent Passing Sample			
		A	B	C	D
4	4.760	92	95	93	77
8	2.380	--	67	65	39
10	2.000	62	61	--	--
16	1.190	--	45	38	19
30	0.590	--	25	19	9
40	0.420	27	--	--	--
50	0.297	--	9	6	4
100	0.149	6	5	1	2
Number of Samples		2	3	2	3
Effective Size Sand, P_{10}		0.17	0.31	0.40	0.68
Uniformity Coefficient, P_{10}/P_{60}		9.7	6.5	5.5	5.1

TABLE 9. PROCEDURES FOR ANALYSES PERFORMED

Analysis	Procedure	Ref. No.
Biochemical Oxygen Demand	Standard Methods	APHA et al., 1971
Chemical Oxygen Demand	Standard Methods	APHA et al., 1971
Suspended Solids	Standard Methods	APHA et al., 1971
Volatile Suspended Solids	Standard Methods	APHA et al., 1971
Total Phosphorus	EPA Methods	EPA, 1974
Orthophosphorus	Strickland and Parsons (Murphy-Riley Technique)	Strickland and Parsons, 1968
Ammonia	Solorzano (Indophenol)	Solorzano, 1969
Nitrite	Strickland and Parsons (Diasotization Method)	Strickland and Parsons, 1968
Nitrate	Strickland and Parsons (Cadmium-Reduction Method)	Strickland and Parsons, 1968
Dissolved Oxygen	Standard Methods	APHA et al., 1971
Temperature	Standard Methods	APHA et al., 1971
pH	Standard Methods	APHA et al., 1971
Alkalinity	Standard Methods	APHA et al., 1971
Total Kjeldahl Nitrogen	EPA Methods	EPA, 1974

SECTION 6

RESULTS AND DISCUSSION

GENERAL

The results of the 12½ month study are presented in Tables A-1 through A-9 of Appendix A. The different effective size sands, 0.17 mm, 0.40 mm, and 0.68 mm were evaluated to determine the effects on intermittent sand filter effluent quality. After approximately 11 months of data collection, the sand in Filter No. 3 (0.68 mm effective size) receiving a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) was replaced with 0.31 mm effective size sand to broaden the spectrum of comparison between the different effective size sands.

HYDRAULIC LOADING RATES AND APPLICATION RATES

During the initial stages of the study, high hydraulic loading rates produced short filter run lengths, thus it was necessary to reduce the hydraulic loading rates on four of the six prototype intermittent sand filters. The hydraulic loading rates employed on the 0.68 mm effective size sand (Filters No. 3 and 4) were reduced from 14,031 m^3/ha·d (1.5 MGAD) and 28,061 m^3/ha·d (3.0 MGAD), respectively, to 9354 m^3/ha·d (1.0 MGAD), respectively. The hydraulic loading rates employed on the filters with 0.40 mm effective size sand (Filters No. 2 and 5) were reduced from 14,031 m^3/ha·d (1.5 MGAD) and 28,062 m^3/ha.d (3.0 MGAD), respectively, to 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD), respectively. These new hydraulic loading rates were maintained during the major portion of the study. The 0.17 mm effective size sand filters (Filters No. 1 and 6) operated at hydraulic loading rates of 3742 m^3/ha·d (0.4 MGAD) and 1871 m^3/ha·d (0.2 MGAD) respectively throughout the study.

As shown in Figure 3, the Logan Lagoon System consists of seven cells; however, the primary cells (Cells A_1 and A_2) and the secondary cells (Cells B_1 and B_2) are in parallel. Thus, the system consists of five cells in series. Primary effluent is defined as originating from either Cell A_1 or Cell A_2. Secondary effluent is defined as originating from either Cell B_1 or Cell B_2.

Secondary lagoon effluent from Cell B_1 was applied daily to the six prototype intermittent sand filters from August 15, 1975, to August 25, 1976. However, after May 9, 1976, the 0.40 mm effective size sand filter receiving a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) (Filter No. 2) was loaded with primary lagoon effluents from Cell A_2 twice weekly at one-sixth the application rate previously employed. The influent applied to the 0.40 mm effective size sand filter (Filter No. 2) was changed to accommodate a chlorination experiment, which was conducted concurrently with this study. Initial performance results of applying primary lagoon effluent with an application rate of 0.008 m^3/sec (0.29 cfs) on the 0.40 mm effective size sand filter (Filter No. 2) indicated that the application rate of wastewater to the filter may be an important operational parameter. The application rate is defined as the volume of influent applied per unit time, expressed as cubic meters per second or cubic feet per second, while the hydraulic loading rate is defined as the volume of influent applied per unit area per unit time, often expressed as cubic meters per hectare per day or gallons per acre per day.

To evaluate the effects of filter application rate an overall filter performance, beginning on June 2, 1976, the application rate employed on the 0.68 mm effective size sand filter (Filter No. 4) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) was reduced from 0.048 m^3/sec (1.74 cfs) to 0.008 m^3/sec (0.29 cfs). In addition, on July 19, 1976, the application rate on the 0.40 mm effective size sand filter (Filter No. 5) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) was reduced from 0.048 m^3/sec (1.74 cfs) to 0.008 m^3/sec (0.29 cfs). Thus, the 0.40 mm and 0.68 mm effective size filter sands (Filters No. 4 and 5, respectively) were employed to evaluate the effects of application rate on filter effluent quality. The effect of application rate on the performance of the 0.31 mm effective size filter sand was evaluated not due to a lack of time and the effect of application rate on the 0.17 mm effective size filter sand was not evaluated because this sand produced an excellent quality effluent under the higher application rate (0.048 m^3/sec (1.74 cfs)).

BIOCHEMICAL OXYGEN DEMAND REMOVAL EFFICIENCY

General

The biochemical oxygen demand (BOD_5) performance of all the intermittent sand filters with respect to various effective size sands, hydraulic loading rates and application rates is illustrated in Table 10 and Figure 6. Yearly average BOD_5 concentration in the influent applied to the filters (secondary lagoon effluent) was 11 mg/l with the daily BOD_5 concentration ranging from 3 mg/l to 22 mg/l throughout the study. A complete listing of the filter influent and effluent BOD_5 concentrations is presented in Tables A-1 through A-7 of Appendix A.

Efficiency of 0.68 mm Effective Size Sand

The effluent BOD_5 concentration from the 0.68 mm effective size sand filter (Filter No. 4) with a high hydraulic loading rate of 28,062 m^3/ha·d (3.0 MGAD), averaged 7 mg/l and varied from 3 mg/l to 12 mg/l. The filter run length was 10 days. Though the effluent BOD_5 concentration was satisfactory, the filter run length is probably unsatisfactory for economical intermittent sand filter operation. More operating and maintenance data are needed for a complete economic evaluation.

TABLE 10. SUMMARY OF THE FIVE-DAY BIOCHEMICAL OXYGEN DEMAND PERFORMANCE

Effective Size Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent BOD$_5$ (mg/l)			Effluent BOD$_5$ (mg/l)			Average Percent Removal
			Min.	Max.	Ave.	Min.	Max.	Ave.	
0.17	1,871	0.048	3	22	11	0.3	4	1	90.1
0.17	3,742	0.048	3	22	12	0.1	7	3	77.2
0.31	9,354	0.048	5	21	14	5	11	8	43.5
0.31	9,354	0.008	10	10	10	6	6	6	33.7
0.40	9,354	0.048	3	22	11	4	18	8	21.9
0.40	9,354	0.008	5	20	12	4	11	5	56.0
0.40	14,031	0.048	10	12	11	4	6	5	53.3
0.40	18,708	0.048	3	22	11	3	23	9	23.9
0.40	28,062	0.048	10	10	10	5	5	5	54.6[+]
0.68	9,354	0.048	3	22	12	4	17	8	28.8
0.68	9,354	0.008	4	21	13	3	15	8	39.8
0.68	14,031	0.048	4	13	8	4	7	6	27.5
0.68	18,708	0.048	3	22	12	3	16	9	21.0
0.68	28,602	0.048	6	13	9	3	12	7	27.1
Loaded With Primary Lagoon Effluent Twice Weekly									
0.40	9,354	0.008	9	76	27	4	28	11	60.8

[+] Based on one observation.

Lowering the hydraulic loading rate of the 0.68 mm effective size sand filters (Filters No. 3 and 4) to 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD), respectively, resulted in no significant change in the effluent BOD$_5$ concentration. The mean effluent BOD$_5$ concentration was 9 mg/l and daily values varied from 3 mg/l to 17 mg/l. The 0.68 mm effective size sand filters (Filters No. 3 and 4) produced a BOD$_5$ concentration of less than 5 mg/l during 20 percent of the study. The daily effluent BOD$_5$ concentrations were less than or equal to 10 mg/l (State of Utah, Class C Regulation) during less than 25 percent of the study.

Lowering the rate of application on the 0.68 mm effective size sand filter (Filter No. 4) from 0.048 m^3/sec (1.69 cfs) to 0.008 m^3/sec (0.29 cfs) while applying a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) improved BOD$_5$ removal. The mean effluent BOD$_5$ concentration during this short period of study was 8 mg/l, with daily values varying from 3 mg/l to 15 mg/l. High influent zooplankton concentrations were observed during this period of the study. Zooplankton are more easily filtered because of their greater size when compared with algae. Therefore, the increased performance exhibited by

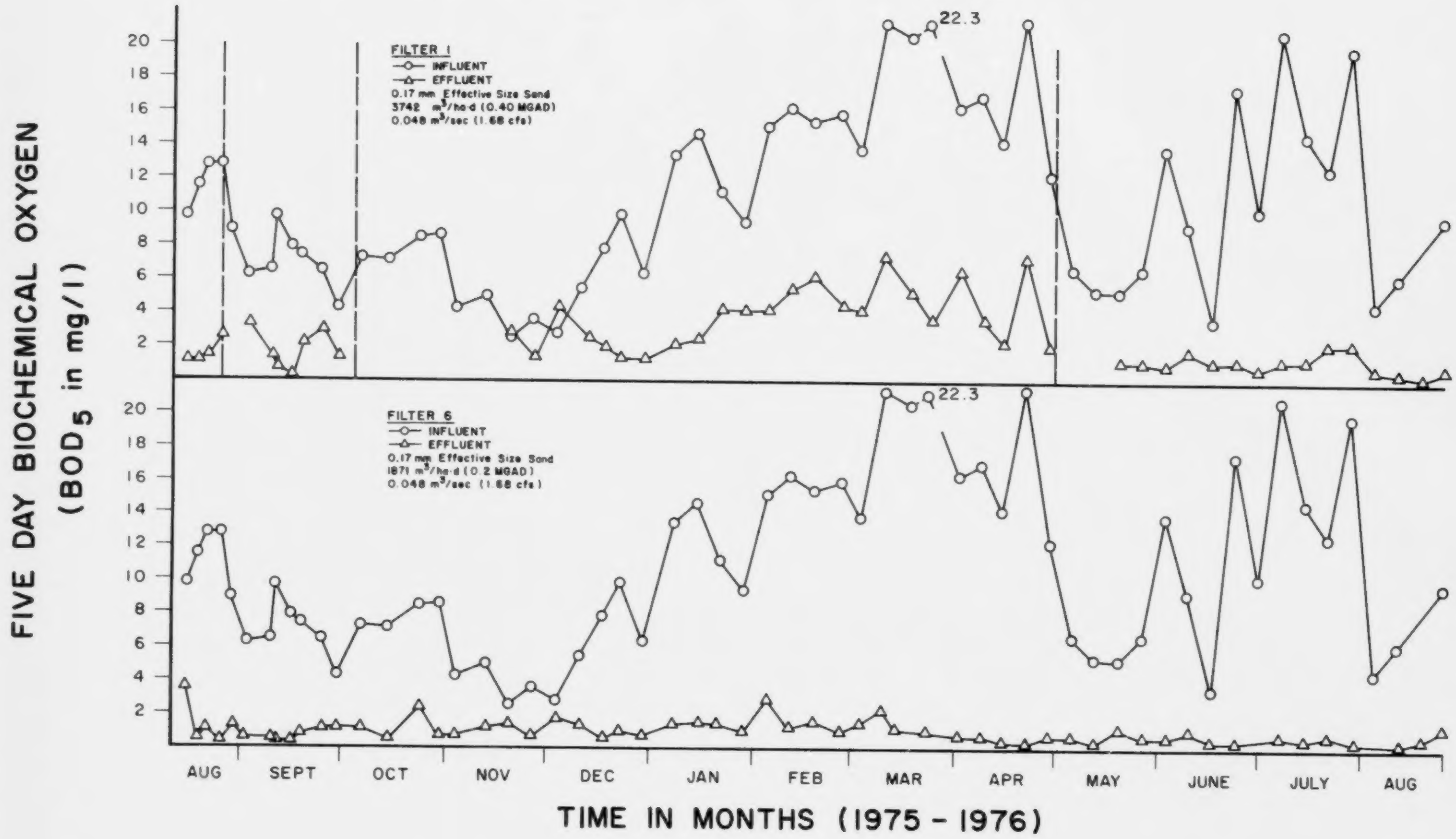


Figure 6. Weekly biochemical oxygen demand (BOD_5) performance.

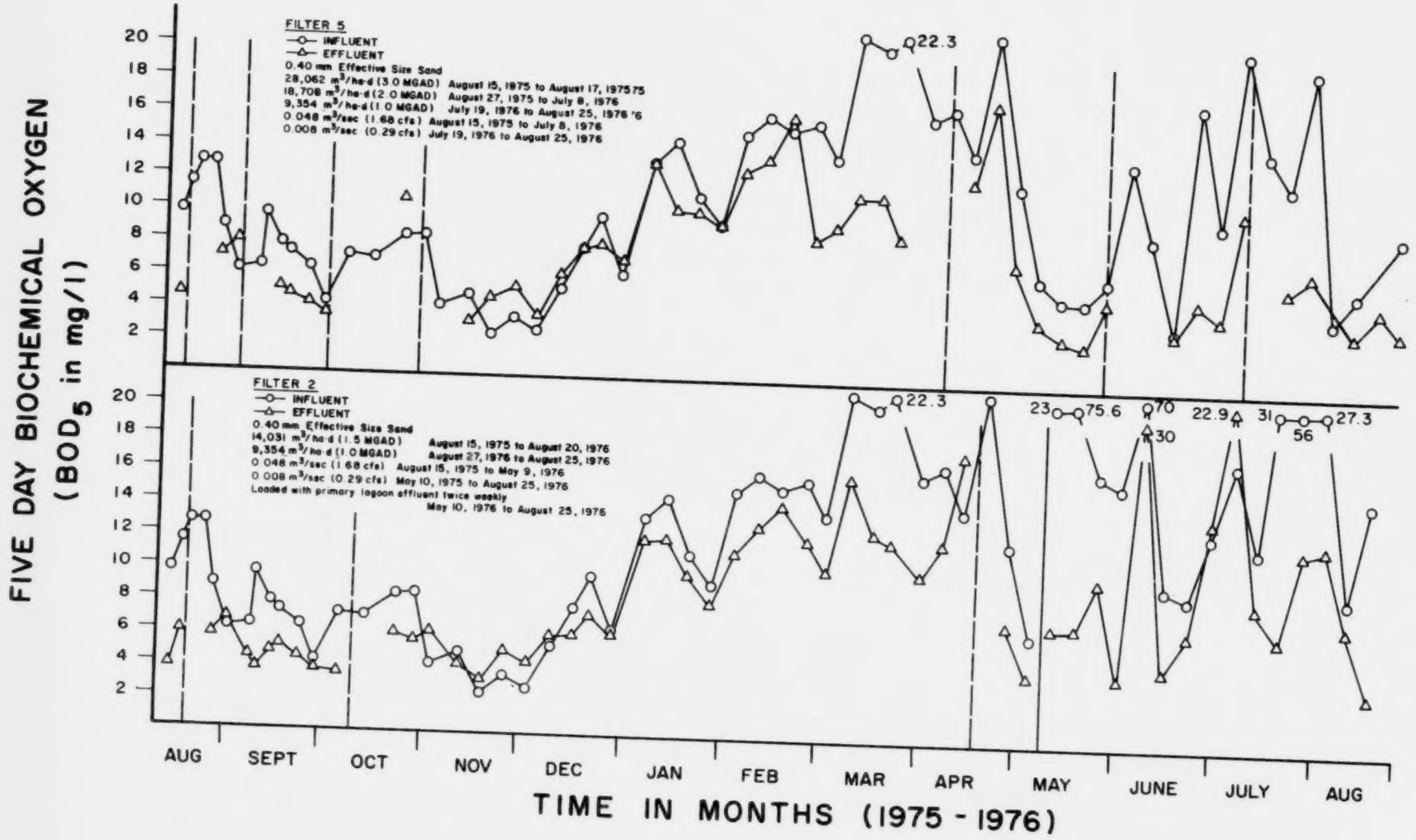
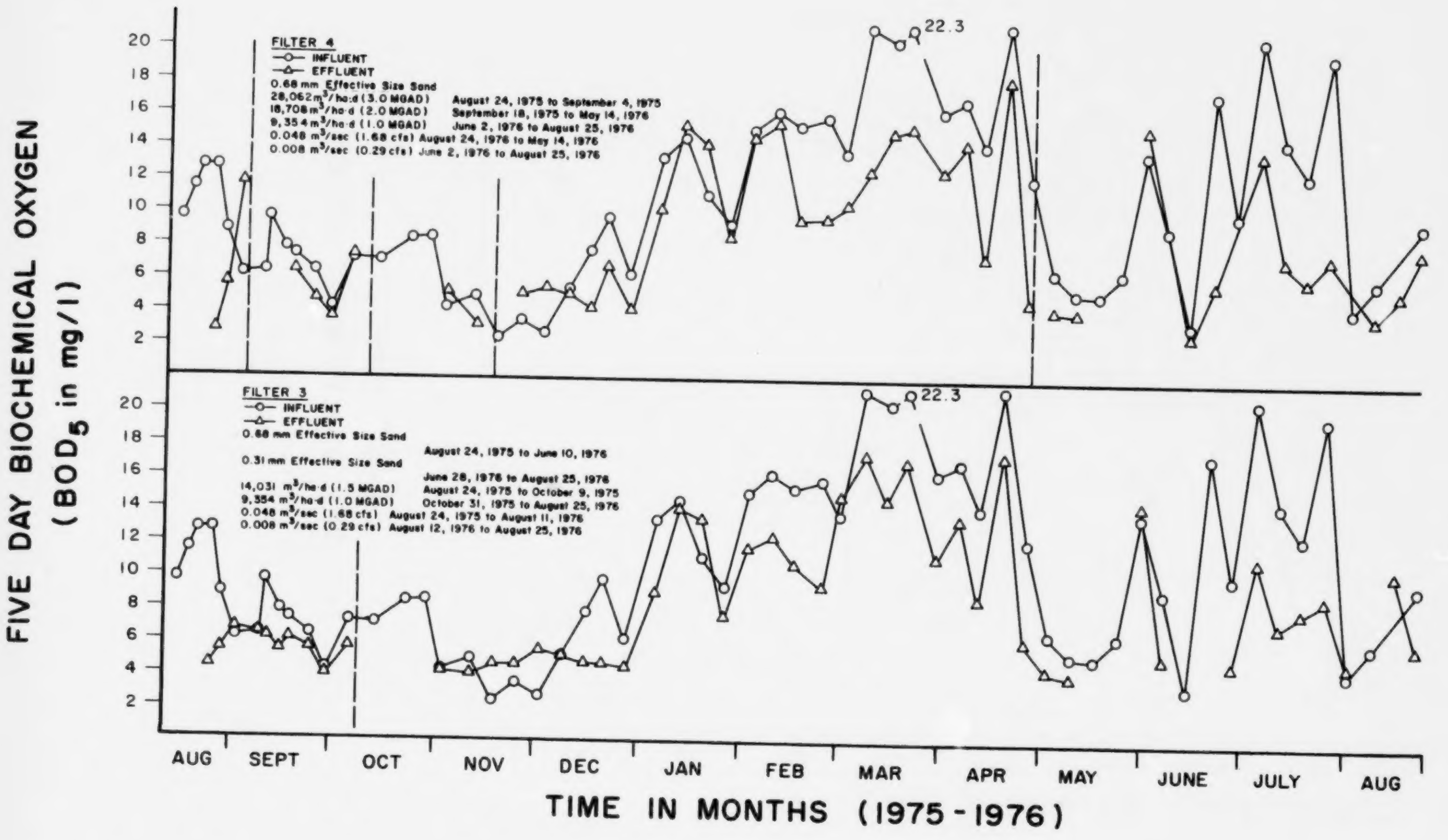


Figure 6. Continued.


FIVE DAY BIOCHEMICAL OXYGEN
(BOD$_5$ in mg/l)
20
18
16
14
12
10
8
6
4
2
FILTER 4
INFLUENT
EFFLUENT
0.68 mm Effective Size Sand
28,062 m^3/ha·d (3.0 MGAD) August 24, 1975 to September 4, 1975
18,708 m^3/ha·d (2.0 MGAD) September 18, 1975 to May 14, 1976
9,354 m^3/ha·d (1.0 MGAD) June 2, 1976 to August 25, 1976
0.048 m^3/sec (1.68 cfs) August 24, 1976 to May 14, 1976
0.008 m^3/sec (0.29 cfs) June 2, 1976 to August 25, 1976
22.3
FILTER 3
INFLUENT
EFFLUENT
0.68 mm Effective Size Sand
August 24, 1975 to June 10, 1976
0.31 mm Effective Size Sand
June 28, 1976 to August 25, 1976
14,031 m^3/ha·d (1.5 MGAD) August 24, 1975 to October 9, 1975
9,354 m^3/ha·d (1.0 MGAD) October 31, 1975 to August 25, 1976
0.048 m^3/sec (1.68 cfs) August 24, 1975 to August 11, 1976
0.008 m^3/sec (0.29 cfs) August 12, 1976 to August 25, 1976
22.3
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
TIME IN MONTHS (1975-1976)

the lower rate of application may be due the change in the nature of the influent composition rather than actual improvement in overall efficiency.

Efficiency of 0.40 mm Effective Size Filter Sand

The initial high hydraulic loading rate of 28,062 m^3/ha·d (3.0 MGAD) on the 0.40 mm effective size sand filter (Filter No. 5) produced an effluent BOD_5 concentration of 5 mg/l. A filter run length of only three days was achieved, but unfortunately a filter run of such short duration is impractical. Therefore, the hydraulic loading rates on the 0.40 mm effective size sand (Filters No. 2 and 5) were decreased from 14,031 m^3/ha·d (1.5 MGAD) and 28,062 m^3/ha·d (3.0 MGAD), respectively, to 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD), respectively. Operating at the lower hydraulic loading rates, the BOD_5 performance decreased slightly; however, the filter run length was increased significantly. These filters (Filters No. 2 and 5) operating at the lower hydraulic loading rates (9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD)) were able to satisfy the State of Utah, 1980 Effluent Standards less than 30 percent of the time. Influent BOD_5 concentrations were too low to permit evaluation of the Federal Secondary Treatment Standards.

On July 19, 1976, the hydraulic loading rate and application rates were lowered on the 0.40 mm effective size sand (Filter No. 5) to 9354 m^3/ha·d (1.0 MGAD) and 0.008 m^3/sec (1.68 cfs) from 18,708 m^3/ha·d (2.0 MGAD) and 0.048 m^3/sec (0.29 cfs) to establish a comparison of effluent quality with low and high rates of application of wastewater. The mean effluent BOD_5 concentration with the low application rate was 5 mg/l and daily values ranged from 4 to 11 mg/l. With these operating conditions, Filter No. 5 was able to satisfy the State of Utah, 1980 Effluent Standards 100 percent of the time. However, a high Daphnia concentration was present in the filter influent at the time of the experiment. Daphnia are more easily removed than algae; thus, the results may not be completely representative of intermittent sand filter operation (Calaway, 1954).

Efficiency of 0.31 mm Effective Size Filter Sand

During the short period of study of the 0.31 mm effective size sand with a hydraulic loading rate of 9354 m^3/ha.d (1.0 MGAD) and an application rate of 0.048 m^3/sec (1.68 cfs), the mean influent BOD_5 concentration was 14 mg/l and daily values ranged from 5 to 21 mg/l. The mean effluent BOD_5 concentration was 8 mg/l and daily values ranged from 5 to 11 mg/l. Again, high BOD_5 performance may be significantly influenced by the high concentration of readily removable Daphnia in the filter influent.

Efficiency of 0.17 mm Effective Size Sand

The 0.17 mm effective size sand (Filters No. 1 and 6) produced an effluent that satisfied the State of Utah, 1980 Effluent Standards of 100 mg/l throughout the entire study. However, influent BOD_5 concentrations were too low to evaluate performance against the Federal Secondary Treatment Standards.

The 0.17 mm effective size sand (Filter No. 6) receiving a hydraulic loading rate of 1871 m^3/ha·d (0.2 MGAD) produced an effluent BOD_5 concentration of less than 5 mg/l throughout the entire study. Effluent BOD_5 concentrations ranged from 0.3 to 4 mg/l. The effluent BOD_5 concentration was less than 2 mg/l 90 percent of the time.

The 0.17 mm effective size sand (Filter No. 1) with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) produced an effluent BOD_5 ranging from 0.1 to 7 mg/l. At no time during the study did the effluent BOD_5 concentration of either of the 0.17 mm effective size sand (Filters No. 1 and 6) exceed 10 mg/l. These results are similar to the BOD_5 performance reported by Marshall and Middlebrooks (1974), Reynolds et al. (1974), Messinger (1976), Bishop (1976), and Hill et al. (1976).

Summary

The BOD_5 removal performance of the 0.40 mm and 0.68 mm effective size sand (Filters No. 2, 3, 4, and 5) with a high application rate of 0.048 m^3/sec (1.68 cfs) was not adequate to produce an effluent that consistently meets the State of Utah, 1980, Effluent Discharge Standard of 10 mg/l. The 0.31 mm effective size sand (Filter No. 3) produced a significant BOD_5 removal; however, the influent characteristics at the time of study indicate that these results are inconclusive. Lowering the application rate on the 0.40 mm (Filter No. 5) and the 0.68 mm (Filter No. 4) effective size sands appeared to increase BOD_5 removal; however, the zooplankton in the influent during that experiment make such a conclusion questionable. The 0.17 mm effective size sand (Filters No. 1 and 6) was shown to be capable of high BOD_5 removal at low hydraulic loading rates of 3742 m^3/ha·d (0.4 MGAD) and 1871 m^3/ha·d (0.2 MGAD). No conclusion can be established with relation to the Federal Secondary Treatment Standards which requires an effluent BOD_5 of 30 mg/l or less because the influent BOD_5 concentration did not exceed 23 mg/l during the entire study period.

CHEMICAL OXYGEN DEMAND PERFORMANCE

General

Chemical oxygen demand (COD) performance of the filters is shown in Table 11 and Figure 7. A complete listing of the filter influent and effluent COD performance is presented in Tables A-1 through A-7, Appendix A. The yearly mean influent COD concentration (secondary lagoon effluent) was 52 mg/l with daily influent COD concentrations ranging from 24 to 36 mg/l.

Efficiency of 0.68 mm Effective Size Sand

Hydraulic loading rates ranging from 9354 m^3/ha·d (1.0 MGAD) to 28,062 m^3/ha·d (3.0 MGAD) were attempted with the 0.68 mm effective size sand (Filters No. 3 and 4). Filter run lengths at the higher hydraulic loading rate of 28,062 m^3/ha·d (3.0 MGAD) were not practical, thus lower hydraulic loading rates were employed.

TABLE 11. YEARLY SUMMARY OF THE CHEMICAL OXYGEN DEMAND PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent COD (mg/l)			Effluent COD (mg/l)			Average Percent Removal
			Min.	Max.	Ave.	Min.	Max.	Ave.	
0.17	1,871	0.048	24	90	51	3	23	11	78
0.17	3,742	0.048	24	136	54	8	35	18	67
0.31	9,354	0.048	51	136	79	40	80	56	30
0.31	9,354	0.008	54	58	56	35	40	37	33
0.40	9,354	0.048	24	77	49	19	48	34	31
0.40	9,354	0.008	51	90	63	35	69	46	28
0.40	14,031	0.048	32	32	32	21	21	21	35
0.40	18,708	0.048	24	136	50	23	78	38	25
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	24	77	45	22	53	36	19
0.68	9,354	0.008	34	136	69	28	86	51	26
0.68	14,031	0.048	48	75	69	36	55	42	39
0.68	18,708	0.048	25	77	48	24	67	39	20
0.68	28,062	0.048	47	90	69	40	79	59	14
Loaded With Primary Lagoon Effluent Twice Weekly									
0.40	9,354	0.008	48	203	84	15	67	40	53

The minimum daily effluent COD concentration from the 0.68 mm filter sand was 22 mg/l at a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) while the maximum daily effluent COD concentration of 86 mg/l occurred at a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) also. However, in general, higher effluent COD concentrations occurred at the higher hydraulic loading rates. A comparison of the mean yearly effluent COD concentrations reported in Table 11 indicates a range from 36 mg/l with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) to 59 mg/l at a hydraulic loading rate of 28,062 m^3/ha·d (3.0 MGAD).

In general, COD percentage removals for all the filter sands is less than 30 percent.

Efficiency of 0.40 mm Effective Size Sand

Hydraulic loading rate appeared to have a slight effect on COD removal by the 0.40 mm effective size sand (Filters No. 2 and 5). The 0.40 mm effective size sand (Filter No. 2) with a hydraulic loading rate of 9354 m^3/ha.d (1.0 MGAD) produced a mean effluent COD concentration of 34 mg/l with a daily range of 19 mg/l to 48 mg/l (Table 11). The 0.40 mm effective size sand with a hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD) produced a mean effluent

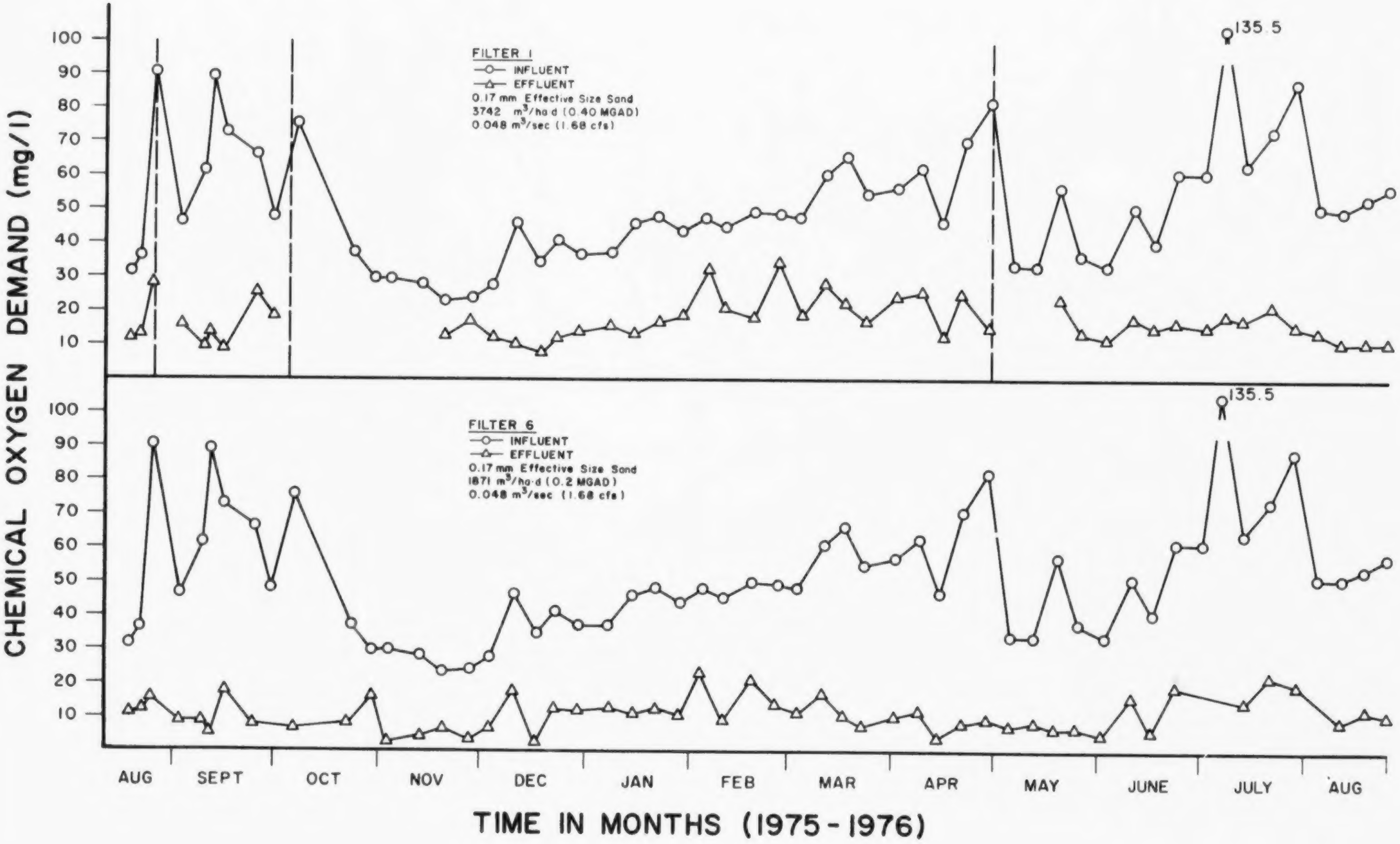


Figure 7. Weekly chemical oxygen demand performance.

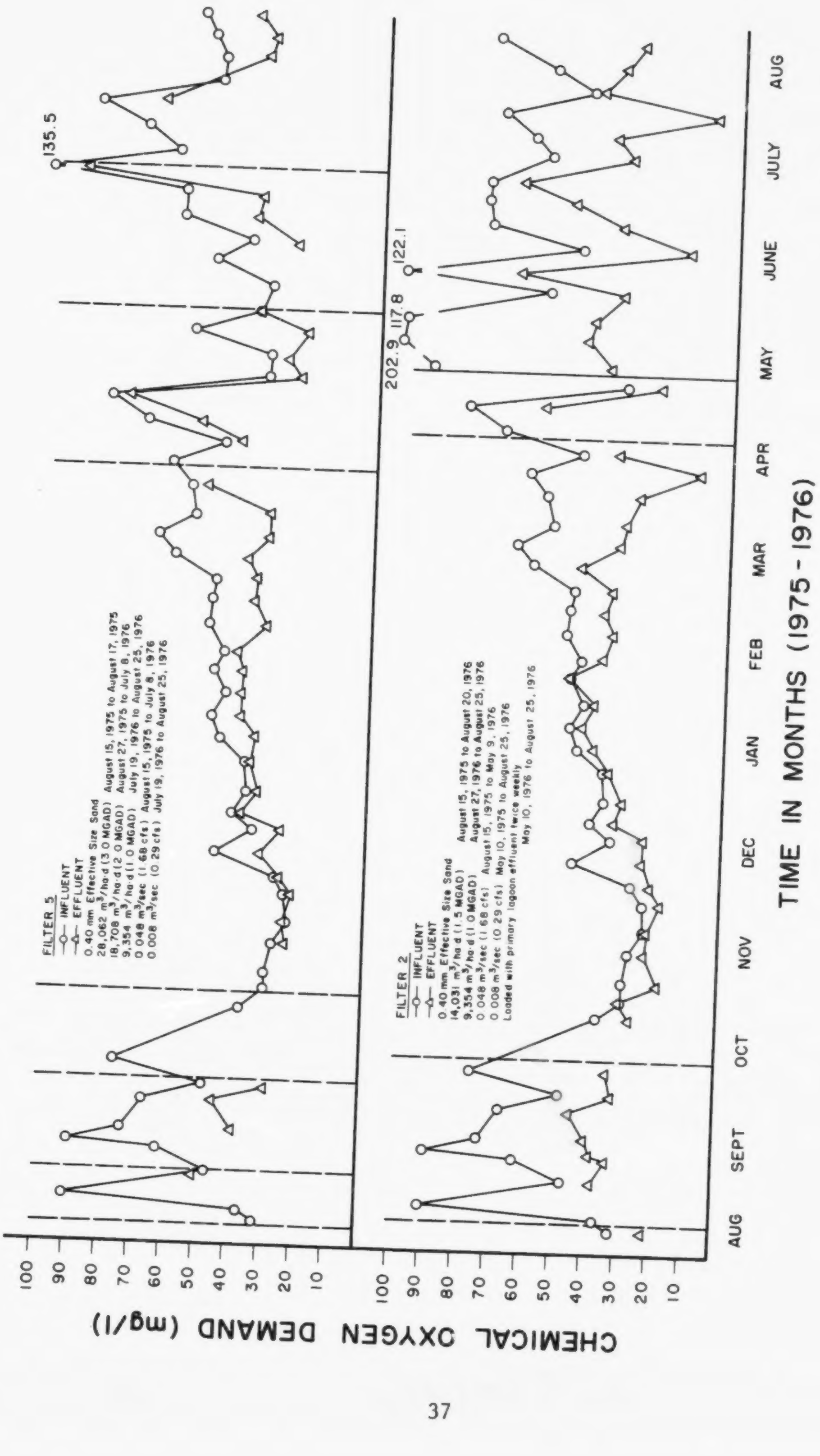


Figure 7. Continued.

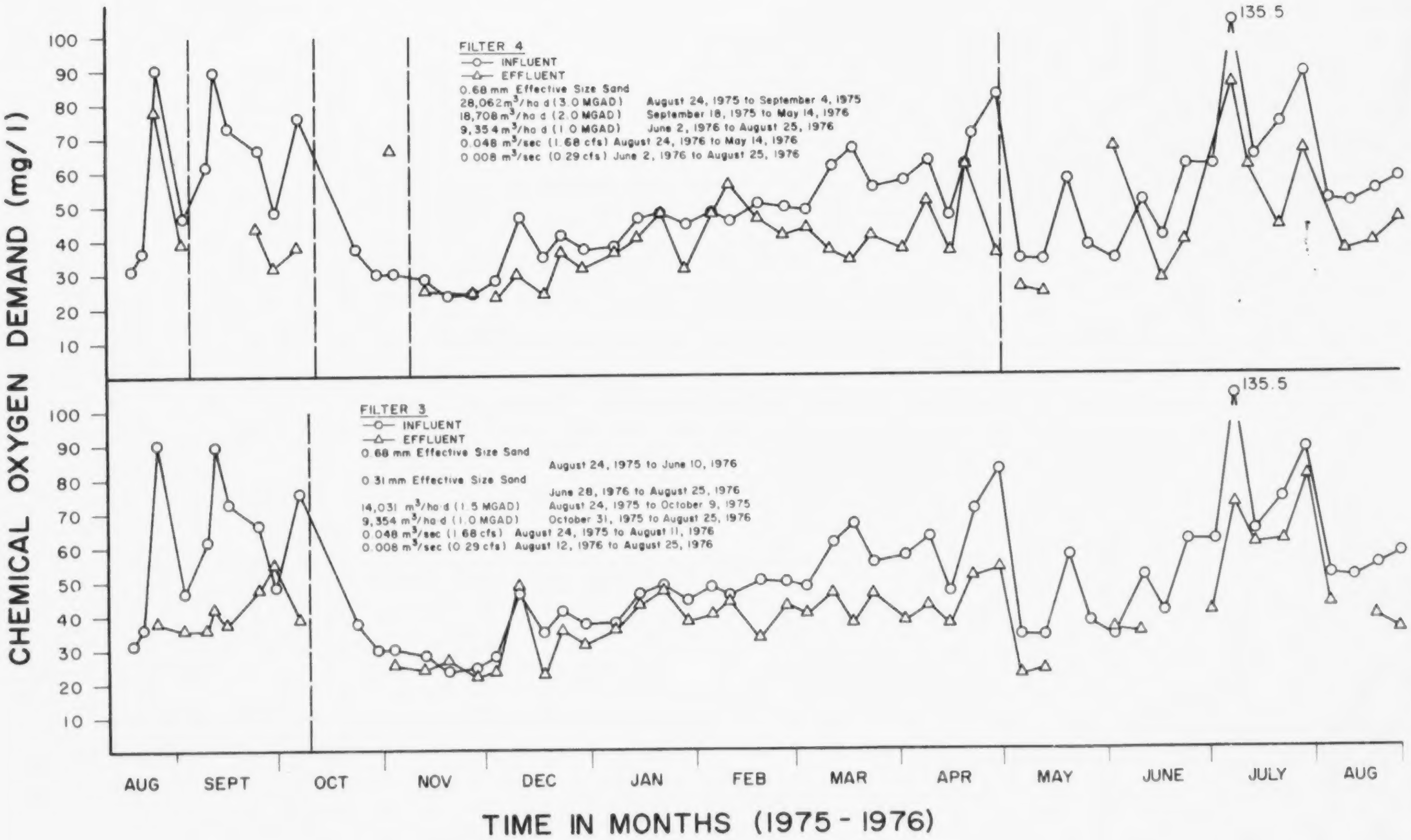


Figure 7. Continued.

COD concentration of 38 mg/1 with the daily values ranging from 23 mg/1 to 78 mg/1. The COD removal by the 0.40 mm effective size sand (Filters No. 2 and 5) does not follow the BOD_5 performance closely.

The 0.40 mm effective size sand (Filter No. 2) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) and an application rate of 0.008 m^3/sec (0.29 cfs) loaded twice weekly with primary lagoon effluent achieved a moderately high COD removal, averaging 53 percent. The mean yearly primary lagoon effluent (filter influent) COD concentration was 84 mg/1 and daily values ranged from 48 to 203 mg/1. The 0.40 mm effective size sand (Filter No. 2) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) and an application rate of 0.008 m^3/sec (0.29 cfs) loaded twice weekly with primary lagoon effluent produced a mean effluent COD concentration of 40 mg/1, and the daily concentrations varied from 15 to 67 mg/1.

Efficiency of 0.31 mm Effective Size Sand

COD removal by the 0.31 mm effective size sand (Filter No. 3) was very similar to the COD performance of the 0.40 mm effective size sand (Filters No. 2 and 5). The 0.31 mm filter (Filter No. 3) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) and an application rate of 0.048 m^3/sec (1.68 cfs) produced a mean effluent COD concentration of 56 mg/1 and the daily concentrations ranged from 40 to 80 mg/1. This compares to a 0.40 mm effective size sand mean of 31 mg/1 (Filter No. 2) and the 46 mg/1 (Filter No. 5) with the same hydraulic loading rate as Filter No. 3.

Efficiency of 0.17 mm Effective Size Sand

COD removal by the 0.17 mm effective size sand (Filters No. 1 and 6) was very similar to the BOD_5 performance reported earlier. The 0.17 mm filter (Filter No. 6) receiving a hydraulic loading of 1871 m^3/ha·d (0.2 MGAD) produced a mean yearly effluent COD concentration of 11 mg/1 and a daily range of 3 to 23 mg/1. This represents a 78 percent removal efficiency. The 0.17 mm sand (Filter No. 1) with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) achieved a mean yearly effluent COD concentration of 18 mg/1 and the daily concentrations varied from 8 to 35 mg/1. This represents a 66 percent removal efficiency.

Summary

Chemical oxygen demand (COD) removal by intermittent sand filters is directly related to the effective size of the sand. In general, COD removal increases as the effective size of the filter sand decreases. Decreasing the hydraulic loading rate generally improved the COD removal. The 0.17 mm effective size sand (Filters No. 1 and 6) with hydraulic loading rates of 1871 m^3/ha·d (0.2 MGAD) and 3742 m^3/ha·d (0.4 MGAD) produced the highest COD removal efficiency of all effective size sands studied.

As discussed in the biochemical oxygen demand (BOD_5) performance section, the low application rate data is insufficient to develop definite conclusions. However, there is some indication that lower application rates increase COD removal performance.

SUSPENDED SOLIDS REMOVAL PERFORMANCE

General

Suspended solids (SS) removal by intermittent sand filters with various effective size sands, hydraulic loading rates and application rates are shown in Table 12 and Figure 8. The mean yearly influent suspended solids concentration (secondary lagoon effluent) was 23 mg/l and the daily SS concentration ranged 3 to 65 mg/l. A complete listing of the filter influent and effluent SS concentrations are shown in Tables A-1 through A-7, Appendix A.

Efficiency of 0.68 mm Effective Size Sand

The mean effluent SS concentration from the 0.68 mm effective size sand (Filter No. 4) with a hydraulic loading rate of 28,062 m^3/ha·d (3.0 MGAD) and an application rate of 0.048 m^3/sec (1.68 cfs) was 35 mg/l and the daily SS concentration varied from 19 mg/l to 58 mg/l. The mean influent SS concentration during this period was 45 mg/l, and the range of daily values was 33 to 52 mg/l. Suspended solids removal under these operating conditions was poor (i.e., less than 22 percent); however, the poor performance is partially attributed to the removal or organic and inorganic material from the filter bed which had accumulated or grown from wastewater application of the previous day. During filter start up, fine inorganic silt or dirt is washed from the sand filter bed. This phenomenon is termed "wash out" (Reynolds et al., 1974) and results from the filter sand not being completely washed prior to installation in the filter. In addition, Reynolds et al. (1974), have reported the growth of algae in the wastewater overlying the filter surface. The high hydraulic loading rate, 28,062 m^3/ha·d (3.0 MGAD) occurred at the beginning of the study and thus the filter bed may not have been completely "washed out" prior to data collection. This is probably a partial cause of the high effluent suspended solids concentration. However, the 0.68 mm effective size sand was not effective in suspended solids removal.

Because of a short filter run length of 11 days for the 0.68 mm effective size sand (Filter No. 4) with a hydraulic loading rate of 28,067 m^3/ha·d (3.0 MGAD), the hydraulic loading rates for the 0.68 mm effective size sand (Filters No. 3 and 4) were lowered to 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD), respectively. Lowering the hydraulic loading rate produced no significant change in SS removal. Even with these lower hydraulic loading rates 0.68 mm effective size sand (Filters No. 3 and 4) was unable to satisfy the State of Utah Effluent Discharge Standard of 10 mg/l over 50 percent of the time. Careful analyses of the data indicated that when the influent suspended solids concentration exceeded 17 mg/l, the 0.68 mm effective size sand effluent suspended solids concentration exceeded 10 mg/l.

As indicated in Figure 8, the 0.68 mm effective size filter sand removal efficiency was heavily influenced by the influent suspended solids concentration. During periods of high influent suspended solids concentrations, the effluent suspended solids concentrations exceeded 30 mg/l (i.e., Federal Secondary Discharge Standard), thus the 0.68 mm effective size filter sand is not suitable for polishing lagoon effluents to meet stringent discharge standards.

TABLE 12. YEARLY SUMMARY OF THE SUSPENDED SOLIDS PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent SS (mg/l)			Effluent SS (mg/l)			Average Percent Removal
			Min.	Max.	Ave.	Min.	Max.	Ave.	
0.17	1,871	0.048	3	74	23	0.6	24	3	88
0.17	3,742	0.048	3	74	21	0.3	18	3	83
0.31	9,354	0.048	8	65	28	8	29	15	45
0.31	9,354	0.008	20	20	20	10	21	16	22
0.40	9,354	0.048	3	51	19	1	31	13	30
0.40	9,354	0.008	12	36	22	2	16	7	65
0.40	14,031	0.048	34	45	40	11	13	12	71
0.40	18,708	0.048	3	65	18	1	46	12	40
0.40	28,062	0.048	45	45	45	83	83	83	0
0.68	9,354	0.048	3	51	16	2	25	11	29
0.68	9,354	0.008	9	74	34	3	40	15	55
0.68	14,031	0.048	18	52	38	7	30	20	49
0.68	18,708	0.048	3	51	17	3	24	13	22
0.68	28,062	0.048	33	52	45	19	58	35	21
Loaded With Primary Lagoon Effluent Twice Weekly									
0.40	9,354	0.008	11	71	34	3	18	8	77

Lowering the rate of application on the 0.68 mm effective size sand filter (Filter No. 4) from 0.048 m^3/sec (1.68 cfs) to 0.008 m^3/sec (0.29 cfs) while applying a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) reduced the effluent suspended solids concentrations. The mean effluent SS concentration during this short period of the study was 16 mg/l with a daily range of 3 to 40 mg/l. The effluent SS concentration met the State of Utah, 1980 Effluent Standards of 10 mg/l, 67 percent of the time. However, a high concentration of Daphnia was present in the influent; thus, the above data may not be representative of normal intermittent sand filter operation.

Efficiency of 0.40 mm Effective Size Sand

The 0.40 mm effective size sand (Filters No. 2 and 5) with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD) and a high application rate of 0.048 m^3/sec (1.68 cfs) were able to produce an effluent which met the State of Utah, 1980 Effluent Standard of 10 mg/l less than 40 percent of the time during the study. The effluent SS concentration averaged 12 mg/l over the entire study and daily values ranged from 1 to 52 mg/l. The high daily effluent suspended solids concentrations are associated with high influent suspended solids concentrations (see Figure 8), and thus, indicate the inability of this filter sand to satisfy stringent Federal discharge standards.

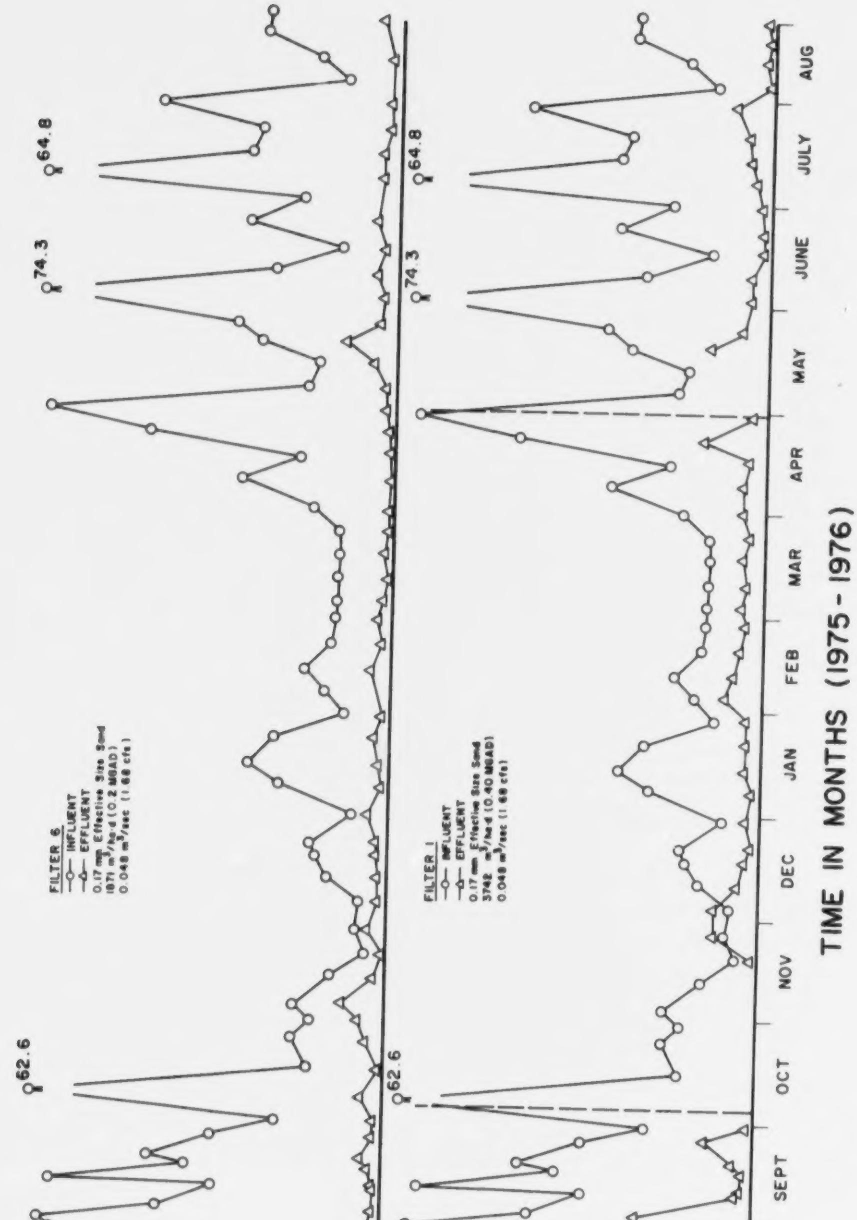


Figure 8. Weekly suspended solids performance.

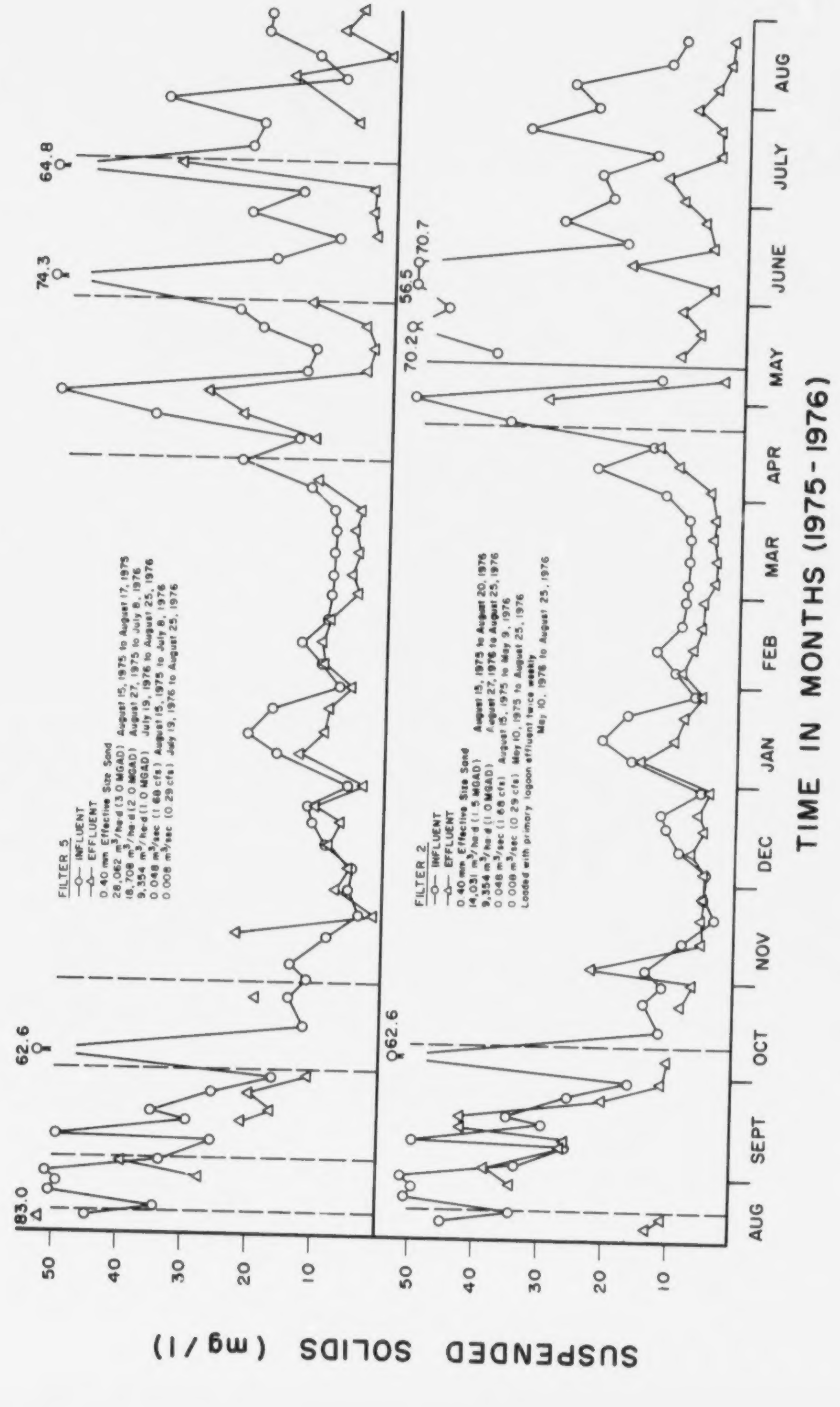


Figure 8. Continued.

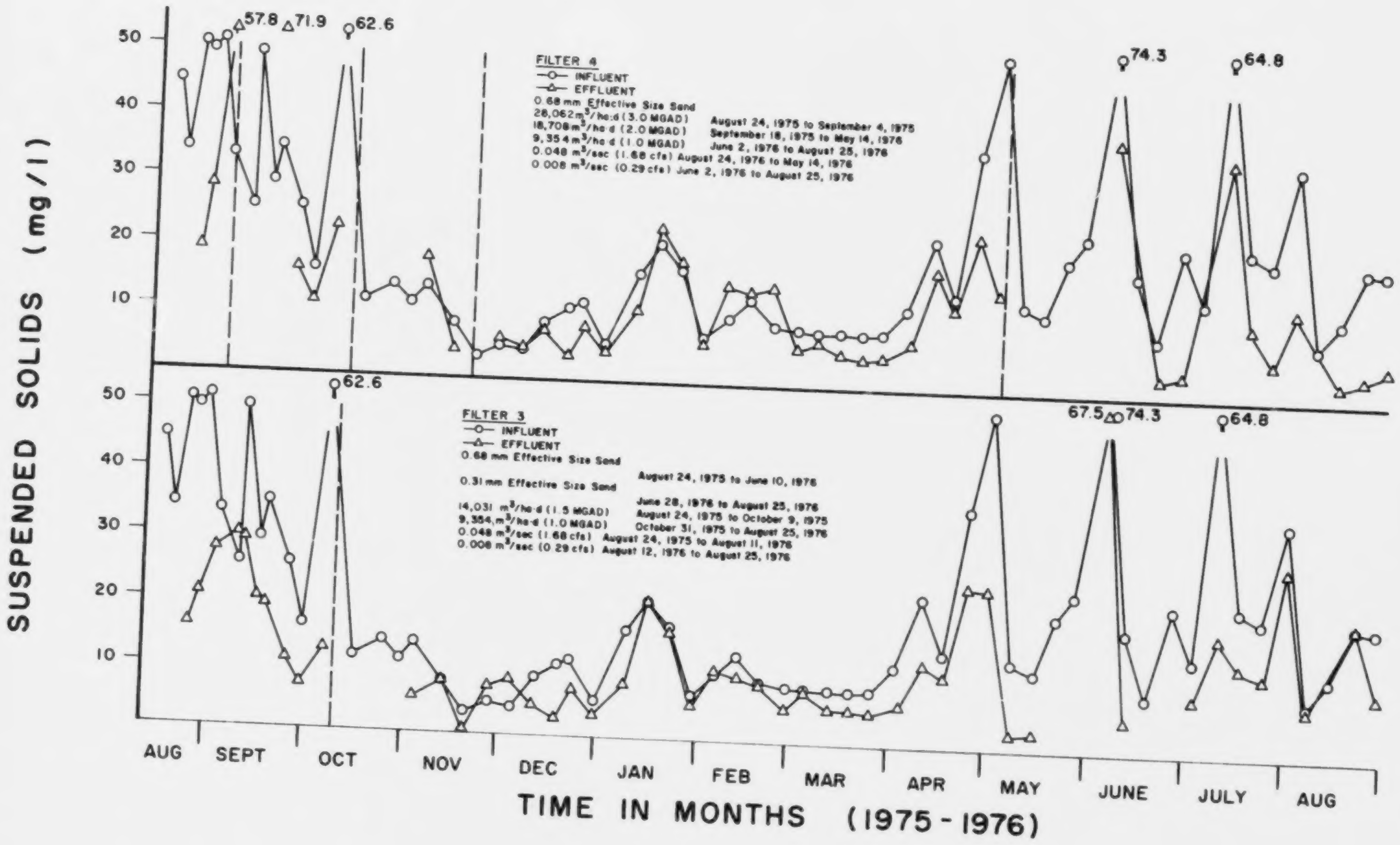


Figure 8. Continued.

Operating these filters with a lower application rate of 0.008 m^3/sec (0.29 cfs) and a hydraulic loading rate of 9354 m^3/ha•d (1.0 MGAD), the 0.40 mm sand (Filter No. 5) produced an effluent which satisfied the State of Utah, 1980 Effluent Standard of 10 mg/l during 80 percent of the study. As before, the influent contained a high concentration of *Daphnia* and thus these results may not be conclusive.

Applying primary lagoon effluent twice weekly, the 0.40 mm filter (Filter No. 2) at a hydraulic loading rate of 9354 m^3/ha•d (1.0 MGAD) and a low application rate of 0.008 m^3/sec (0.29 cfs) produced relatively high quality effluent. The mean effluent SS concentration for this filter was 8 mg/l with a daily range of 3 to 18 mg/l.

Efficiency of 0.31 mm Effective Size Sand

Poor SS removals were obtained with the 0.31 mm effective size sand (Filter No. 3) receiving a hydraulic loading rate of 9354 m^3/ha•d (1.0 MGAD) and a high application rate of 0.048 m^3/sec (1.68 cfs). State of Utah, 1980, standards were met on less than one-third of the sampling days. The mean effluent SS concentration was 15 mg/l and the daily effluent SS concentration ranged from 8 to 29 mg/l.

Efficiency of 0.17 mm Effective Size Sand

The 0.17 mm effective size sand (Filters No. 1 and 6) with hydraulic loading rates of 3742 m^3/ha•d (0.4 MGAD) and 1871 m^3/ha•d (0.2 MGAD) produced a low effluent suspended solids concentration throughout the entire study. Filter No. 1 produced a mean effluent SS concentration of 4 mg/l with daily values ranging from 0.3 to 18 mg/l. Filter No. 6 received a hydraulic loading rate of 1871 m^3/ha.d (0.2 MGAD) and produced a mean effluent SS concentration of 3 mg/l and a daily range of 0.6 to 24 mg/l. The 0.17 mm effective size sand (Filters No. 1 and 6) produced an effluent SS concentration of 30 mg/l or less the entire period of operation and satisfied the State of Utah, 1980 Effluent Standards of 10 mg/l 97 percent of the time.

Summary

The 0.68 mm, 0.40 mm, and the 0.31 mm effective size sands (Filters 2, 3, 4, and 5) with a high application rate of 0.048 m^3/sec (1.68 cfs) were unable to satisfy the State of Utah, 1980 Effluent Standards more than 50 percent of the time. Lowering the application rate to 0.008 m^3/sec (0.29 cfs) on the 0.68 mm and 0.40 mm effective size sand filters (Filters No. 4 and 5) increased suspended solids removal performance and satisfied the State of Utah, 1980 Effluent Standard of 10 mg/l a minimum of 67 percent of the time. The indication that influent suspended solids significantly influenced effluent suspended solids concentrations preclude the use of these filter sands to satisfy stringent discharge standards. It appears that lower application rates increase SS removal, but a definite conclusion cannot be reached due to the short period of study at the lower application rate and the heavy growth of *Daphnia* in the secondary lagoon effluent during the low application rate study.

The 0.40 mm effective size sand (Filter No. 2) with a hydraulic loading rate of 9354 m^3/ha•d (1.0 MGAD) and a low application rate of 0.008 m^3/sec (0.29 cfs) loaded with primary lagoon effluent twice weekly produced high SS removals. Suspended solids removals averaged 76 percent during the study and further indicates that application rate may have a definite effect on SS removal. However, operation of this filter does not represent normal single stage intermittent sand filter operation since lagoon effluent was applied to the filter only twice weekly, rather than daily.

The 0.17 mm effective size sand (Filters No. 1 and 6) with hydraulic loading rates of 3742 m^3/ha•d (0.4 MGAD) and 1871 m^3/ha•d (0.2 MGAD) were capable of meeting the State of Utah, 1980 Effluent Standard of 10 mg/l and the Federal Secondary Discharge Standard of 30 mg/l.

VOLATILE SUSPENDED SOLIDS PERFORMANCE

General

The volatile suspended solids removal obtained with the single stage intermittent sand filters using various effective size sands, hydraulic loading rates and application rates are shown in Table 13 and Figure 9. The mean yearly influent volatile suspended solids (VSS) concentration of the secondary lagoon effluent was 18 mg/l with a minimum daily influent VSS concentration of 2 mg/l and a maximum influent VSS concentration of 68 mg/l. Daily filter influent and effluent VSS concentrations are presented in Tables A-1 through A-7 in Appendix A.

During initial operation of the intermittent sand filters, the volatile suspended solids removal was not directly related to the suspended solids removal because of the wash-out of fine inorganic material from the filter. This inorganic material is present initially in the filter sand because the sand was not washed prior to installation in the filter. But, after approximately 30 days of operation the SS performance was observed to be similar to VSS performance. Hill et al. (1975) and Hill et al. (1976) reported a similar experience.

Efficiency of 0.68 mm Effective Size Sand

Hydraulic loading rate had little influence on volatile suspended solids (VSS) performance. During the fall, winter, and spring months of the study the 0.68 mm sand (Filters No. 3 and 4) with hydraulic loading rates of 9354 m^3/ha•d (1.0 MGAD) and 18,708 m^3/ha•d (2.0 MGAD) achieved VSS removals of 37 percent and 38 percent, respectively. The effluent VSS concentration of Filter No. 3 receiving a hydraulic loading rate of 9354 m^3/ha•d (1.0 MGAD) averaged 9 mg/l and ranged from 2 to 23 mg/l during the study. The effluent volatile suspended solids concentration of Filter No. 4 with a hydraulic loading rate of 18,708 m^3/ha•d (20 MGAD) averaged 8 mg/l and ranged from less than 1 to 23 mg/l.

TABLE 13. YEARLY SUMMARY OF THE VOLATILE SUSPENDED SOLIDS PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent VSS (mg/l) Min.	Influent VSS (mg/l) Max.	Influent VSS (mg/l) Ave.	Effluent VSS (mg/l) Min.	Effluent VSS (mg/l) Max.	Effluent VSS (mg/l) Ave.	Average Percent Removal
0.17	1,871	0.048	2	68	18	0.1	3	1	95
0.17	3,742	0.048	2	68	19	0.2	9	2	88
0.31	9,354	0.048	7	62	25	2	27	12	54
0.31	9,354	0.008	16	17	17	3	3	3	82
0.40	9,354	0.048	3	47	14	1	27	5	64
0.40	9,354	0.008	7	32	19	1	15	5	72
0.40	14,031	0.048	24	33	29	4	5	5	84
0.40	18,708	0.048	2	62	24	1	32	7	70
0.40	28,062	0.048	33	33	33	8	8	8	75
0.68	9,354	0.048	2	48	14	2	23	9	37
0.68	9,354	0.008	5	68	26	2	37	11	57
0.68	14,031	0.048	9	45	25	3	13	7	74
0.68	18,708	0.048	2	47	13	0.3	23	8	38
0.68	28,062	0.048	23	36	31	9	17	13	58
Loaded With Primary Lagoon Effluent Twice Weekly									
0.40	9,354	0.008	9	64	35	2	7	4	88

Efficiency of 0.40 mm Effective Size Sand

Volatile suspended solids removal by the 0.40 mm effective size sand (Filters No. 2 and 5) with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD) was relatively good. Average influent VSS removal rates of 64 percent and 70 percent, respectively, were observed. The 0.40 mm sand (Filter No. 2) produced a mean effluent VSS concentration of 5 mg/l with daily concentrations ranging from 1 to 27 mg/l. Filter No. 5 receiving a hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD), produced a mean effluent VSS concentration of 7 mg/l with daily values ranging from 1 to 32 mg/l. When the application rate of Filter No. 5 was lowered to 0.008 m^3/sec (0.29 cfs) and the hydraulic loading rate was lowered to 9354 m^3/ha·d (1.0 MGAD), the 0.40 mm sand (Filter No. 5) did not show any significant improvement in VSS performance when compared with the higher application rate of 0.048 m^3/sec (1.68 cfs). However, when primary lagoon effluent was applied twice weekly to this same filter (Filter No. 2) at the same hydraulic loading rate (9354 m^3/ha·d (1.0 MGAD)) and same application rate (0.008 m^3/sec (0.29 cfs)) high VSS removals occurred. Under these conditions (i.e., primary lagoon effluent, hydraulic loading rate = 9354 m^3/ha·d, application rate = 0.008 m^3/sec) the effluent VSS concentration of Filter No. 5 averaged 4 mg/l, and individual concentrations ranged from 2 to 7 mg/l.

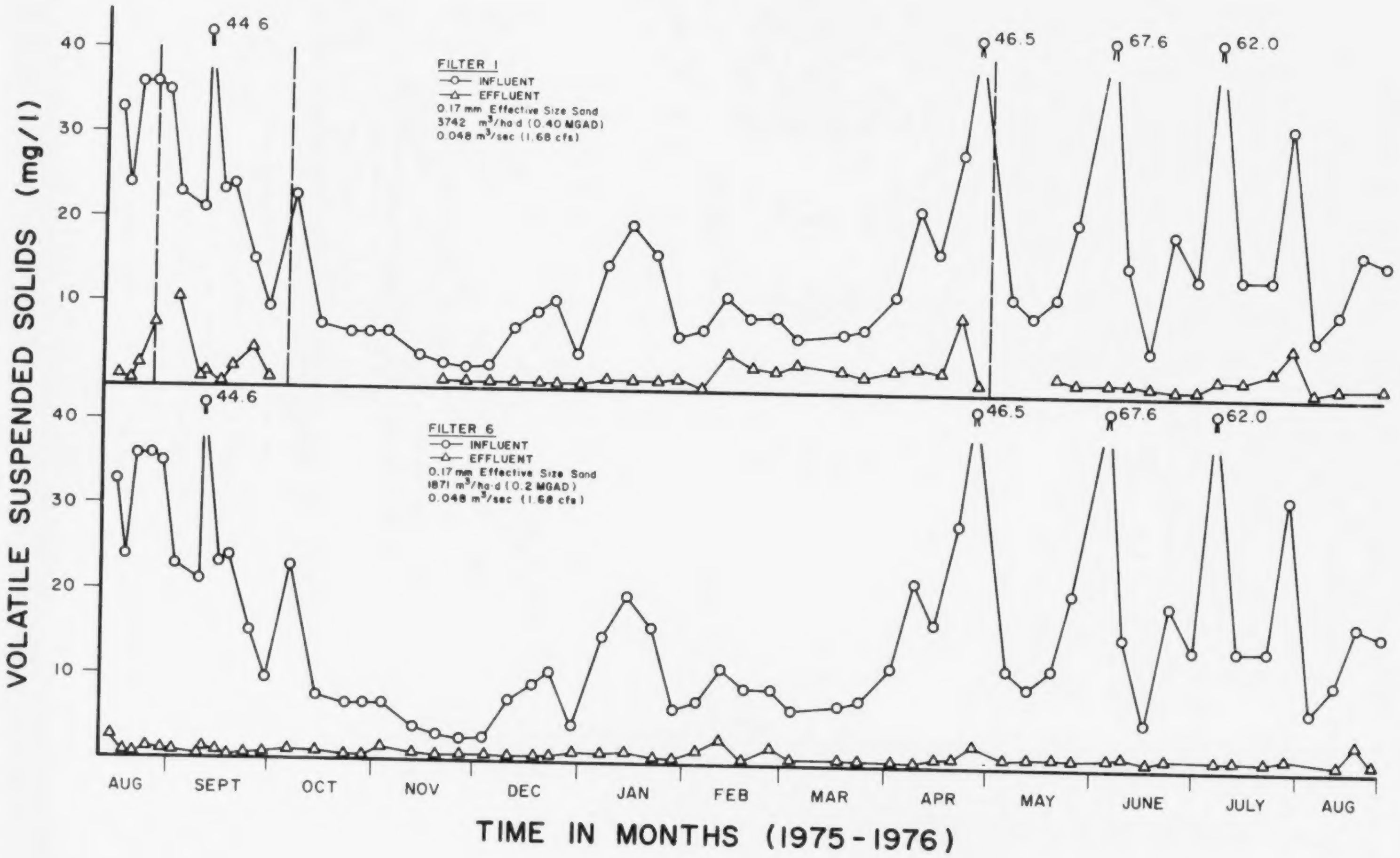


Figure 9. Weekly volatile suspended solids performance.

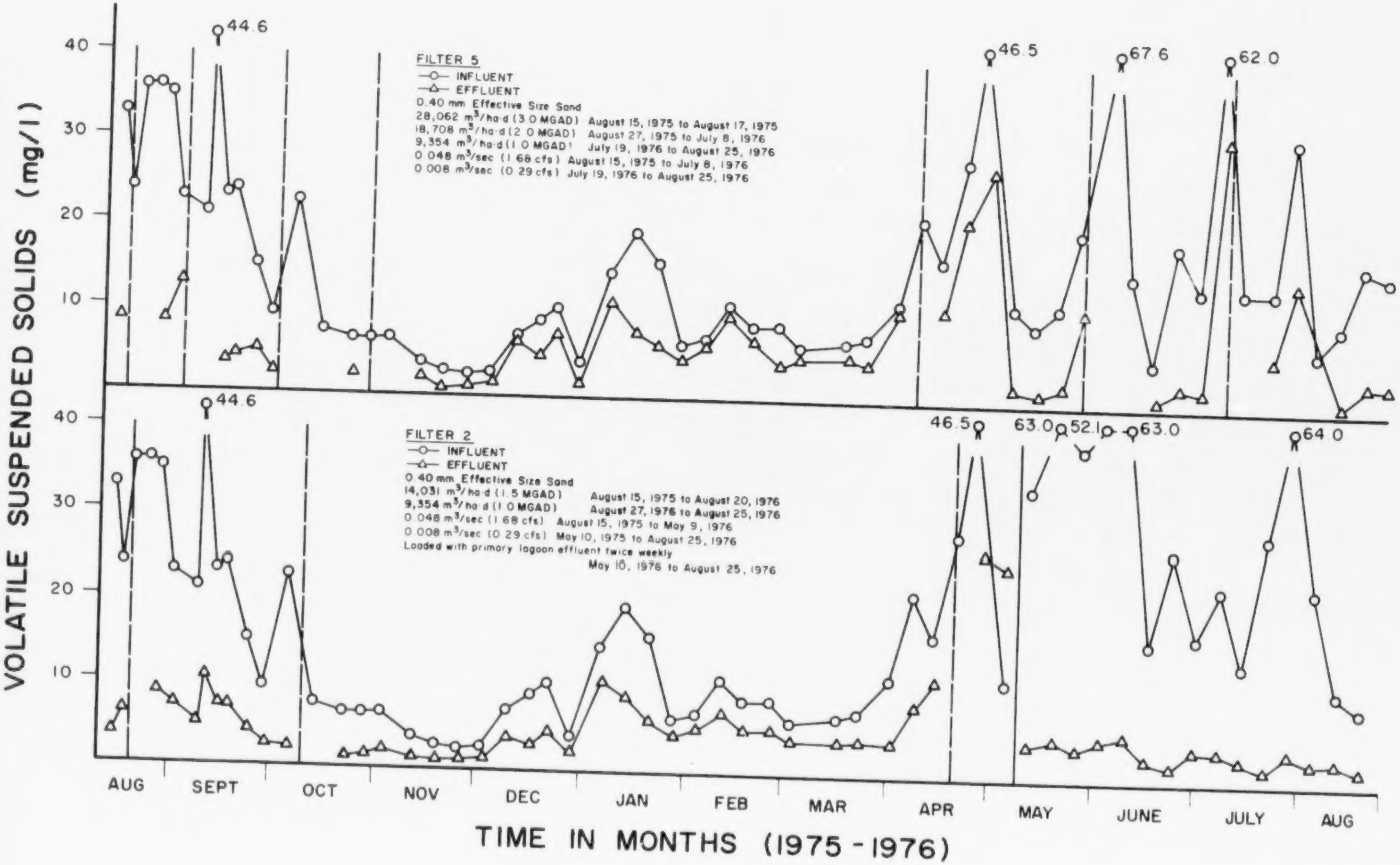


Figure 9. Continued.

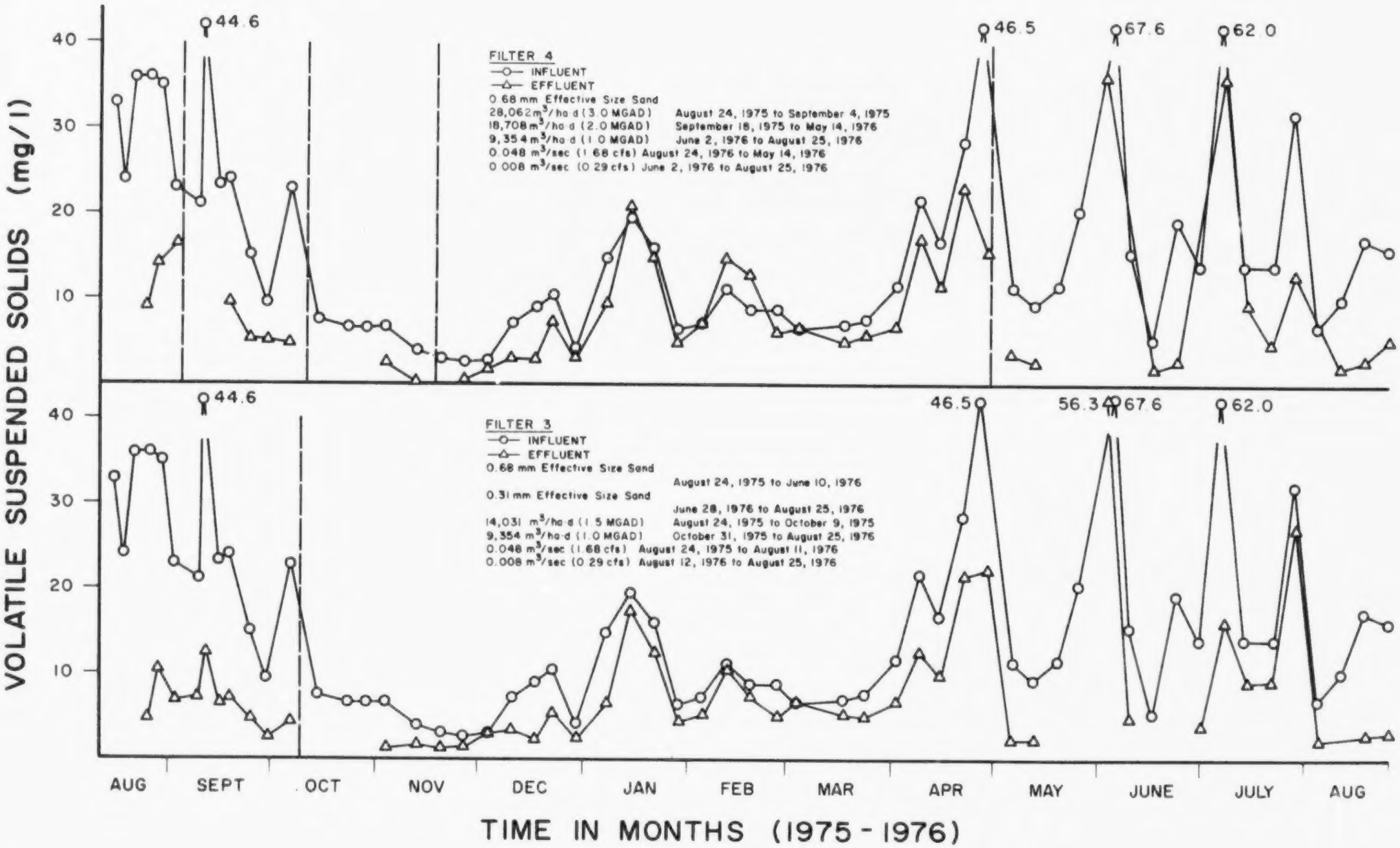


Figure 9. Continued.

Efficiency of 0.31 mm Effective Size Sand

Volatile suspended solids removals by the 0.31 mm sand (Filter No. 3) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) and a high application rate of 0.048 m^3/sec (1.68 cfs) was slightly less than the 0.40 mm effective size sand (Filter No. 3) under similar operating conditions. The mean effluent VSS concentration of Filter No. 3 was 12 mg/l and daily values ranged from 2 to 27 mg/l. Lowering the application rate to 0.008 m^3/sec (0.29 cfs) improved removals from 54 percent to 82 percent during 14 consecutive days of operation. A heavy Daphnia concentration at the time of sampling and the short period of data collection makes it difficult to draw conclusions from these data.

Efficiency of 0.17 mm Effective Size Sand

Excellent volatile suspended solids removal was obtained with 0.17 mm sand (Filters No. 1 and 6). A mean effluent VSS concentration of 1 mg/l was achieved with the 0.17 mm sand (Filter No. 6) loaded at a rate of 1871 m^3/ha·d (0.2 MGAD). Individual daily sampling concentrations ranged from less than 1 mg/l to 3 mg/l. At a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD), the 0.17 mm sand (Filter No. 1) produced a mean effluent VSS concentration of 2 mg/l with individual concentrations varying from less than 1 to 9 mg/l.

Summary

Hydraulic loading rates did not affect volatile suspended solids performance. However, the effective size of the sand appears to have a profound affect on VSS removal (Figure 10). Lower effective size sands produce lower effluent VSS concentrations.

The effect of the application rate on filter performance was obscured by the presence of high concentrations of Daphnia in the lagoon effluent. However, the limited results of the study suggest that lowering the application rate will increase VSS removal efficiency. Further study is required before the exact impact of application rate on filter VSS performance can be defined.

OXIDATION OF NITROGEN

General

An evaluation of the oxidation of nitrogen by intermittent sand filters was performed by determining the influent and effluent concentrations of ammonia-nitrogen (NH_3-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N) and total Kjeldahl nitrogen (TKN) produced by the various effective size sands, hydraulic loading rates and application rates. The various nitrogen forms present in the filter influent and effluents are shown in Tables 14, 15, 16, and 17 and Figures 11, 12, 13, and 14. Figure 15 illustrates the total nitrogen (TKN + NO_2-N + NO_3-N) performance of the filters.

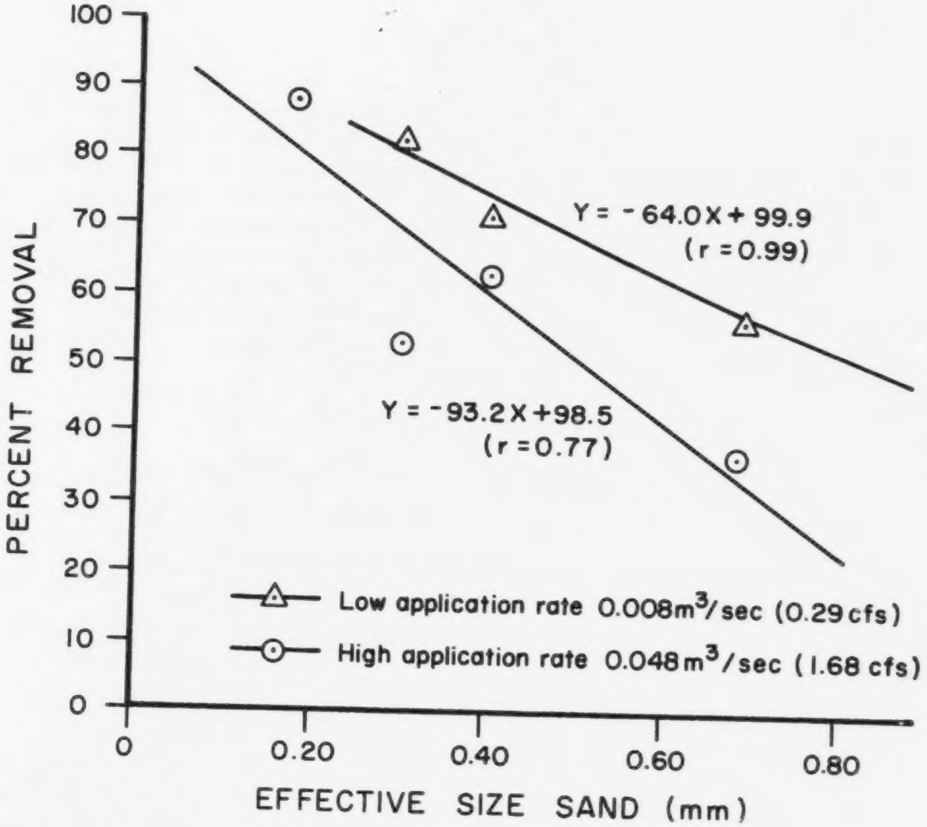


Figure 10. Volatile suspended solids removal efficiency as a function of effective size filter sand; hydraulic loading rate was 9354 m^3/ha·d (1.0 MGAD) for all sand filters, except the 0.17 mm effective size sand filter which was operated at a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD).

Efficiency of 0.68 mm Effective Size Sand

Nitrogen oxidation in the 0.68 mm effective size sand (Filters No. 3 and 4) with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and application rates of 0.048 m^3/sec (1.68 cfs) was relatively low. The nitrate-nitrogen concentration of the lagoon effluent after passing through these filters (Filter No. 3 and 4) only increased from <0.1 mg/l to between 0.3 and 0.7 mg/l. The respective ammonia-nitrogen concentrations remained relatively unchanged at approximately 5 mg/l (see Table 14).

Lowering the application rate on the 0.68 mm sand (Filter No. 4) from 0.048 m^3/sec (1.68 cfs) to 0.008 m^3/sec (0.29 cfs) increased the rate of nitrification slightly. The nitrate-nitrogen concentration of the lagoon effluent passing through the filters increased from <0.1 to 1.3 mg/l, with a

TABLE 14. YEARLY SUMMARY OF THE AMMONIA-NITROGEN PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent NH_3-N			Effluent NH_3-N		
			Min.	Max.	Ave.	Min.	Max.	Ave.
0.17	1,871	0.048	<0.1	8.5	3.2	<0.1	2.2	2.4
0.17	3,742	0.048	<0.1	8.5	3.2	<0.1	6.9	1.9
0.31	9,354	0.048	1.0	3.1	1.3	<0.1	1.3	0.8
0.31	9,354	0.008	1.0	1.2	1.0	<0.1	0.3	0.2
0.40	9,354	0.048	<0.1	8.5	4.7	1.0	8.1	3.5
0.40	9,354	0.008	1.0	1.3	1.1	<0.1	1.0	0.5
0.40	14,031	0.048	1.0	1.0	1.0	1.0	1.0	1.0
0.40	18,708	0.048	<0.1	8.5	4.0	<0.1	8.1	2.7
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	<0.1	8.5	5.0	1.0	7.8	5.1
0.68	9,354	0.008	0.1	3.1	1.0	0.1	1.1	0.6
0.68	14,031	0.048	<0.1	2.6	1.0	<0.2	1.4	0.5
0.68	18,708	0.048	0.1	8.5	5.0	<0.1	8.1	4.3
0.68	28,062	0.048	<0.1	<0.1	0.1	0.1	1.1	0.4
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	<0.8	7.4	4.0	<0.4	3.4	2.0

N.A. = Not available.

corresponding reduction in the ammonia-nitrogen concentration from 1.0 to 0.6 mg/l.

As illustrated in Figure 15, approximately 7 percent of the total nitrogen in the wastewater is removed by the filters. This loss of nitrogen may be due to solids deposition in the filter bed, removal with sand scrapings, or lost to the atmosphere.

Efficiency of 0.40 mm Effective Size Sand

The 0.40 mm effective size sand (Filters No. 2 and 5) produced a more nitrified effluent than the 0.68 mm sand (Filters No. 3 and 4). Receiving hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD) and an application rate of 0.48 m^3/sec (1.68 cfs), the 0.40 mm effective size sand (Filters No. 2 and 5) produced a mean effluent nitrate-nitrogen concentration of 1.2 mg/l while daily values ranged from <0.1 mg/l to 12.0 mg/l. The mean influent nitrate-nitrogen concentration was <0.1 mg/l while daily values ranged from <0.1 mg/l to 0.2 mg/l. The corresponding lagoon effluent TKN concentrations decreased from 7.7 to 6.2 mg/l and the ammonia-nitrogen concentrations decreased from 4.2 to 3.1 mg/l.

TABLE 15. YEARLY SUMMARY OF THE NITRITE-NITROGEN PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent NO_2-N			Effluent NO_2-N		
			Min.	Max.	Ave.	Min.	Max.	Ave.
0.17	1,871	0.048	<0.1	0.2	<0.1	<0.1	0.2	<0.1
0.17	3,742	0.048	<0.1	0.2	<0.1	<0.1	0.1	<0.1
0.31	9,354	0.048	<0.1	0.1	<0.1	0.1	0.1	0.1
0.31	9,354	0.008	<0.1	<0.1	<0.1	<0.1	0.1	0.1
0.40	9,354	0.048	<0.1	0.6	<0.1	<0.1	0.1	0.1
0.40	9,354	0.008	<0.1	0.1	<0.1	<0.1	<0.1	<0.1
0.40	14,031	0.048	0.2	0.2	0.2	0.3	0.3	0.3
0.40	18,708	0.048	<0.1	0.6	<0.1	<0.1	0.4	<0.1
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	<0.1	0.1	<0.1	<0.1	0.1	<0.1
0.68	9,354	0.008	<0.1	0.1	<0.1	<0.1	0.1	<0.1
0.68	14,031	0.048	<0.1	0.6	0.1	<0.1	0.4	<0.1
0.68	18,708	0.048	<0.1	<0.1	0.1	<0.1	0.4	0.1
0.68	28,062	0.048	<0.1	0.6	0.2	<0.1	0.6	0.2
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	<0.1	<0.5	<0.1	<0.1	<0.2	<0.1

N.A. = Not available.

Decreasing the application rate to 0.008 m^3/sec (0.29 cfs) doubled the nitrogen oxidation performance of the 0.40 mm sand (Filter No. 5) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD). During the last three months (June, July, and August of 1976) of the experiment, the mean influent nitrate-nitrogen concentration was <0.1 mg/l. The three month mean filter effluent nitrate-nitrogen concentration was 0.9 mg/l and daily concentrations ranged between 0.2 mg/l and 1.5 mg/l. During this same period the average wastewater TKN concentrations decreased from 5.1 to 2.7 mg/l. The mean filter influent ammonia-nitrogen concentration was 1.1 mg/l and daily values varied from 0.9 to 1.3 mg/l. The mean filter effluent ammonia-nitrogen concentration was 0.5 mg/l and daily concentrations ranged between 0.2 and 1.0 mg/l.

The 0.40 mm effective size sand (Filter No. 2) treating primary lagoon effluent applied twice weekly at an application rate of 0.008 m^3/sec (0.29 cfs) produced a well nitrified effluent. The mean influent nitrate-nitrogen concentration increased from 0.2 to 5.2 mg/l in the effluent. The mean influent ammonia-nitrogen concentration was decreased from 4.0 to 2.0 mg/l. The wastewater TKN concentrations decreased from 7.7 to 4.4 mg/l when passed through this same filter (Filter No. 2).

TABLE 16. YEARLY SUMMARY OF THE NITRATE-NITROGEN PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent NO$_3$-N (mg/l)			Effluent NO$_3$-N (mg/l)		
			Min.	Max.	Ave.	Min.	Max.	Ave.
0.17	1,871	0.048	<0.1	0.5	0.1	1.6	9.5	4.0
0.17	3,742	0.048	<0.1	0.5	0.1	0.2	9.1	2.9
0.31	9,354	0.048	<0.1	<0.1	<0.1	0.1	0.3	0.2
0.31	9,354	0.008	<0.1	<0.1	<0.1	0.4	1.1	0.7
0.40	9,354	0.048	<0.1	0.2	0.1	0.2	8.2	1.2
0.40	9,354	0.008	<0.1	<0.1	<0.1	0.2	1.5	0.7
0.40	14,031	0.048	0.5	0.5	0.5	1.8	1.8	1.8
0.40	18,708	0.048	<0.1	0.2	0.1	<0.1	12.0	1.2
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	<0.1	0.2	0.7	<0.1	0.9	0.3
0.68	9,354	0.008	<0.1	0.1	<0.1	0.7	4.0	1.3
0.68	14,031	0.048	<0.1	0.2	0.1	<0.1	4.1	0.8
0.68	18,708	0.048	<0.1	0.2	0.2	<0.1	5.6	0.7
0.68	28,062	0.048	<0.1	<0.1	<0.1	<0.1	1.3	0.4
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	<0.1	<0.7	<0.2	<1.7	13.7	5.2

N.A. = Not available.

Efficiency of 0.31 mm Effective Size Sand

Very little oxidation of ammonia-nitrogen to nitrate-nitrogen occurred in the 0.31 mm effective size sand (Filter No. 3) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) with an application rate of 0.048 m^3/sec (1.68 cfs). The mean nitrate-nitrogen concentration of the wastewater only increased from <0.1 mg/l to 0.2 mg/l while the mean ammonia concentration decreased from 1.1 mg/l to 0.5 mg/l. The corresponding mean TKN concentrations decreased from 5.1 mg/l to 3.2 mg/l.

Lowering the application rate from 0.048 m^3/day (1.68 cfs) to 0.008 m^3/day (0.29 cfs) increased nitrification slightly with the wastewater mean nitrate-nitrogen concentration increasing from <0.1 to 0.7 mg/l. The corresponding mean ammonia-nitrogen concentration decreased from 1.0 to 0.2 mg/l while the corresponding mean TKN concentrations decreased from 3.5 to 2.1 mg/l.

Figure 15 indicates an average loss of total nitrogen of 30 percent with the 0.31 mm sand.

TABLE 17. YEARLY SUMMARY OF THE TOTAL KJELDAHL NITROGEN PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent TKN (mg/l)			Effluent TKN (mg/l)		
			Min.	Max.	Ave.	Min.	Max.	Ave.
0.17	1,871	0.048	1.0	14.0	6.8	0.2	7.5	2.2
0.17	3,742	0.048	1.0	14.0	7.1	0.2	9.6	3.7
0.31	9,354	0.048	3.6	6.9	5.1	2.3	4.5	3.2
0.31	9,354	0.008	3.5	3.5	3.5	2.1	2.1	2.1
0.40	9,354	0.048	2.1	14.0	8.1	1.6	11.3	6.6
0.40	9,354	0.008	4.4	6.5	5.1	1.4	3.3	2.7
0.40	14,031	0.048	5.4	5.4	5.4	2.9	2.9	2.9
0.40	18,708	0.048	1.0	14.0	7.3	1.0	11.8	5.7
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	1.8	14.0	8.3	1.4	10.9	7.4
0.68	9,354	0.008	1.9	8.6	5.0	1.4	6.2	3.3
0.68	14,031	0.048	2.4	11.8	5.7	2.7	12.9	5.7
0.68	18,708	0.048	1.8	14.0	8.5	1.4	1.3	7.5
0.68	28,062	0.048	2.4	4.9	4.1	2.6	3.6	3.1
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	3.4	15.1	7.7	2.6	7.5	4.4

N.A. = Not available.

Efficiency of 0.17 mm Effective Size Sand

The greatest oxidation of ammonia-nitrogen occurred in the 0.17 mm effective size sands (Filters No. 1 and 6). The average influent ammonia-nitrogen concentration in the lagoon effluent treated by the 0.17 mm effective size sands (Filter No. 6) with a hydraulic loading rate of 1871 m^3/ha·d (0.2 MGAD) was reduced from 3.2 mg/l to 2.4 mg/l. The corresponding average nitrate-nitrogen concentration increased from <0.1 mg/l to 4.0 mg/l after passage through the filter. The average TKN concentration in the wastewater passing through the 0.17 mm effective size sand decreased from 6.8 mg/l to 2.2 mg/l.

With a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD), the 0.17 mm effective size sand (Filter No. 1) reduced the average lagoon effluent ammonia-nitrogen concentration from 3.2 to 1.9 mg/l. This is a slightly greater reduction than the 1871 m^3/ha·d (0.2 MGAD) hydraulic loading rate but is not significantly different. The corresponding average nitrate-nitrogen concentration in the wastewater increased from 0.1 to 2.9 mg/l, while the corresponding TKN concentration was reduced from 7.1 to 3.7 mg/l.

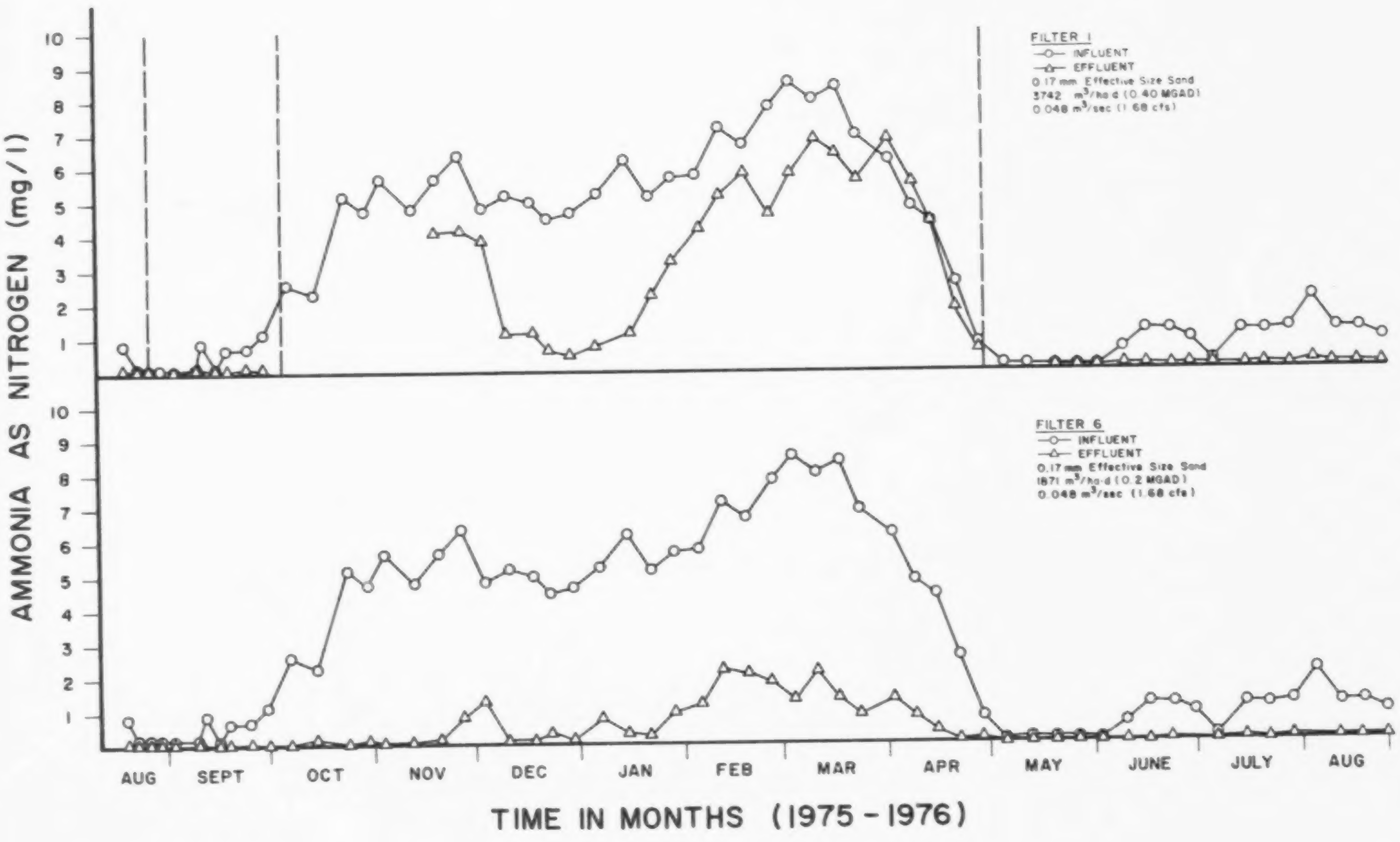


Figure 11. Weekly ammonia-nitrogen performance.

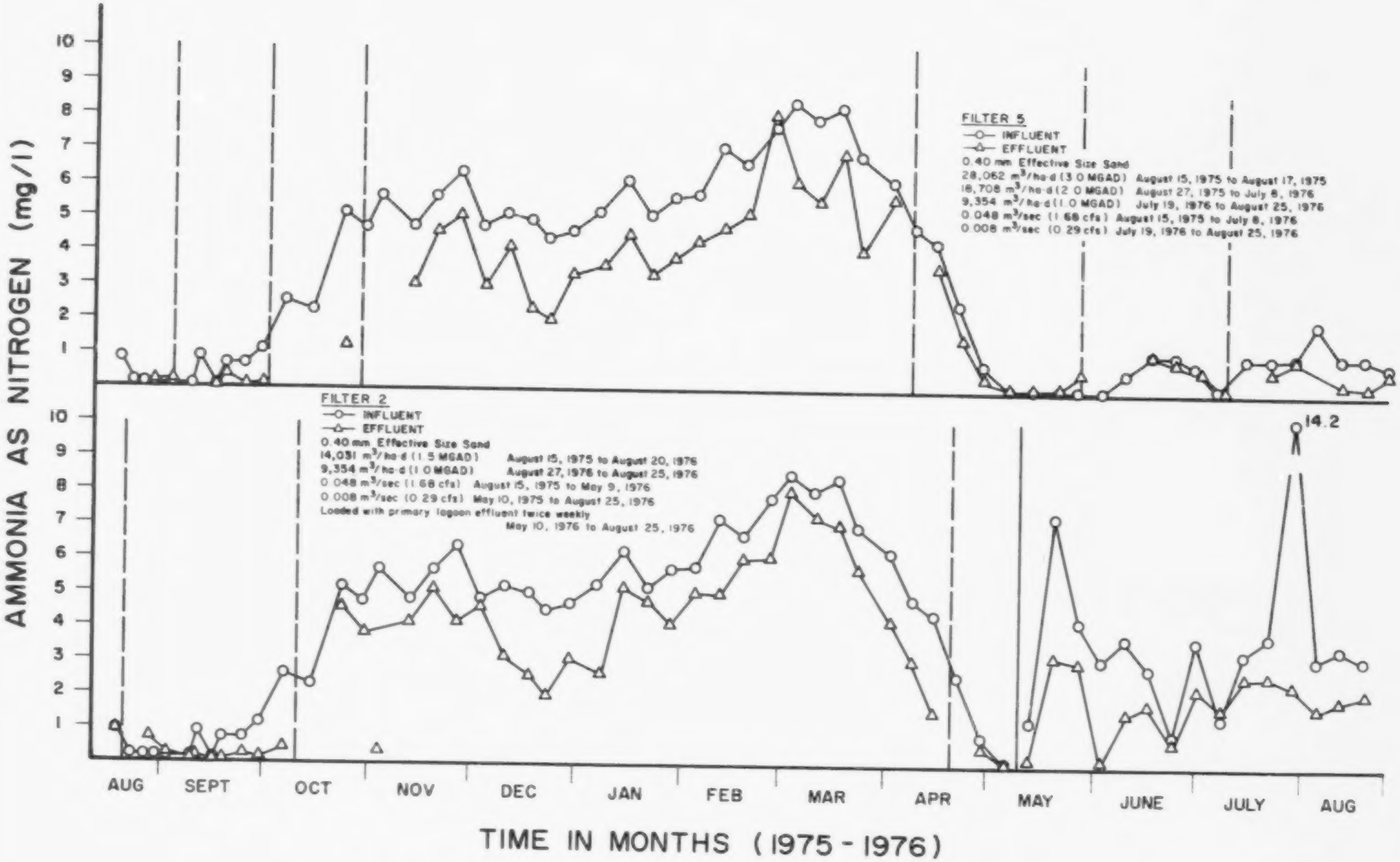


Figure 11. Continued.

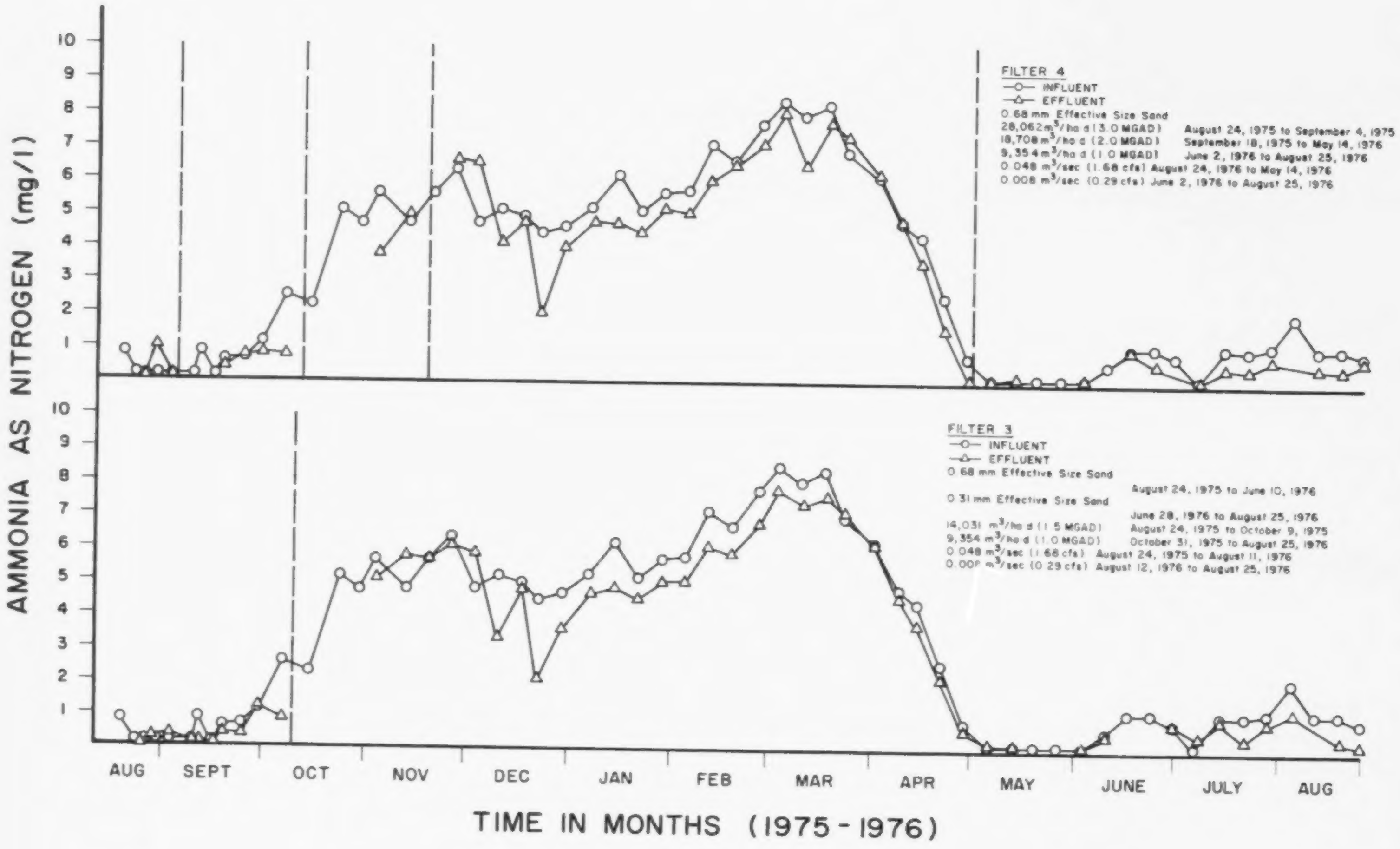


Figure 11. Continued.

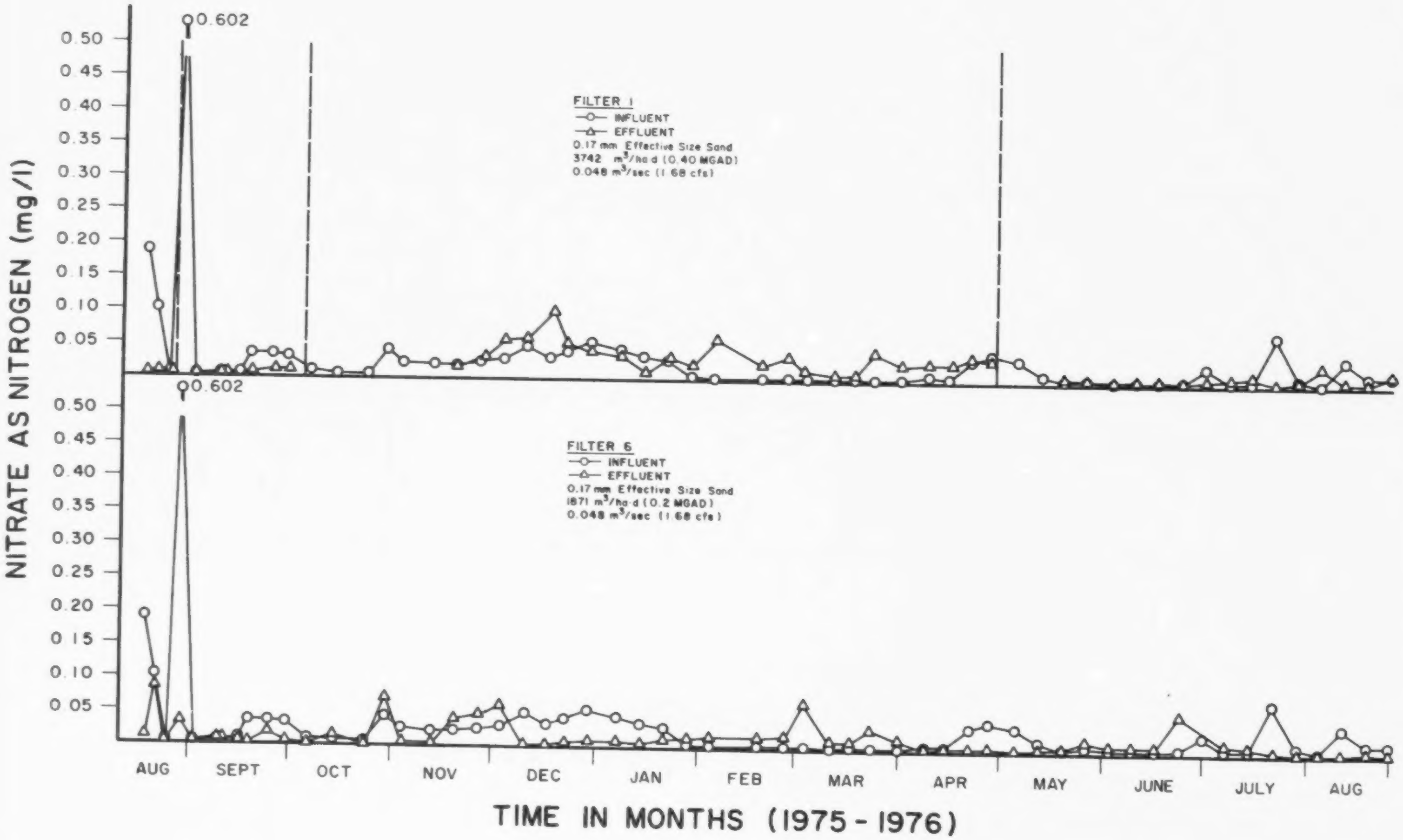
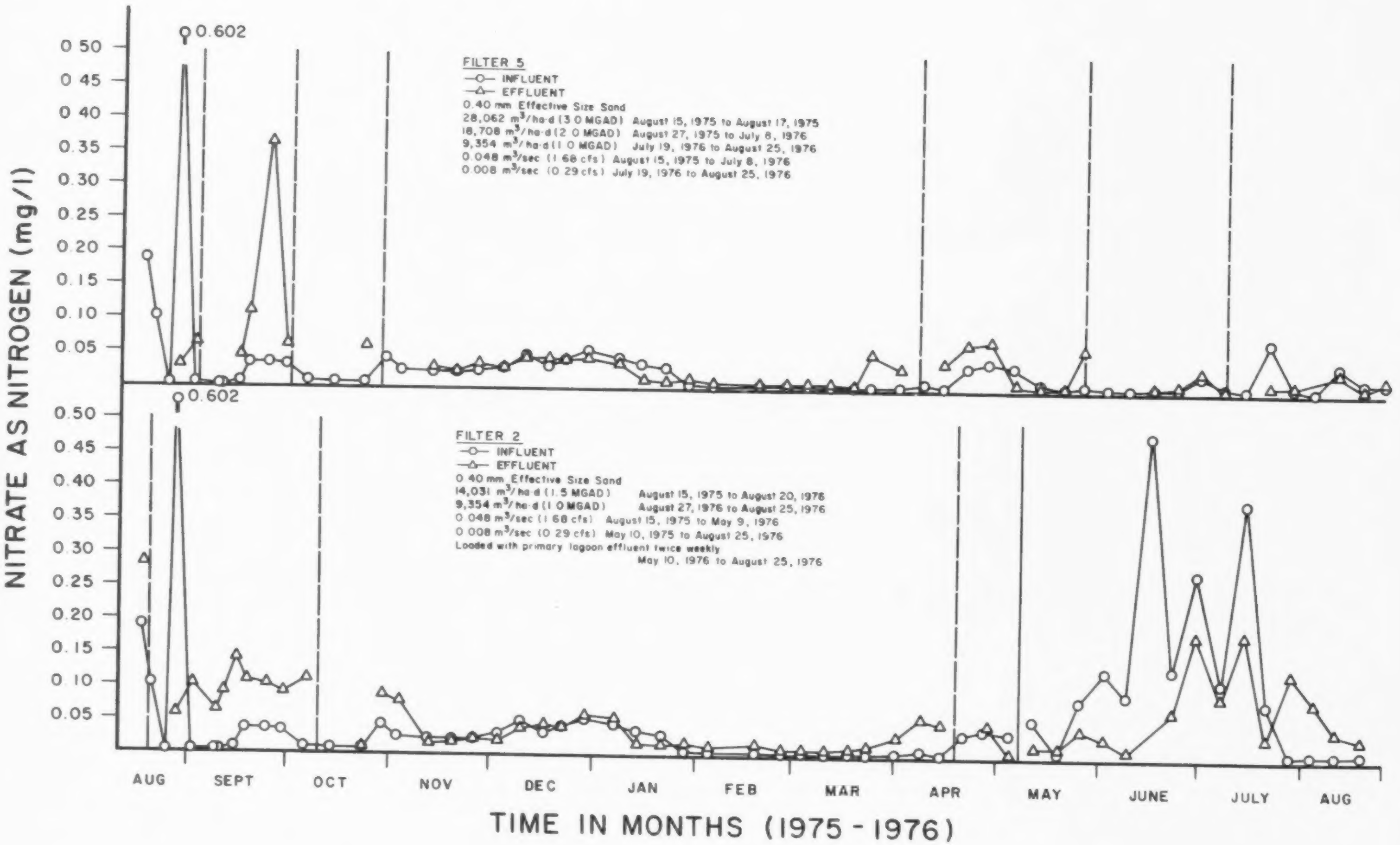


Figure 12. Weekly nitrite-nitrogen performance.



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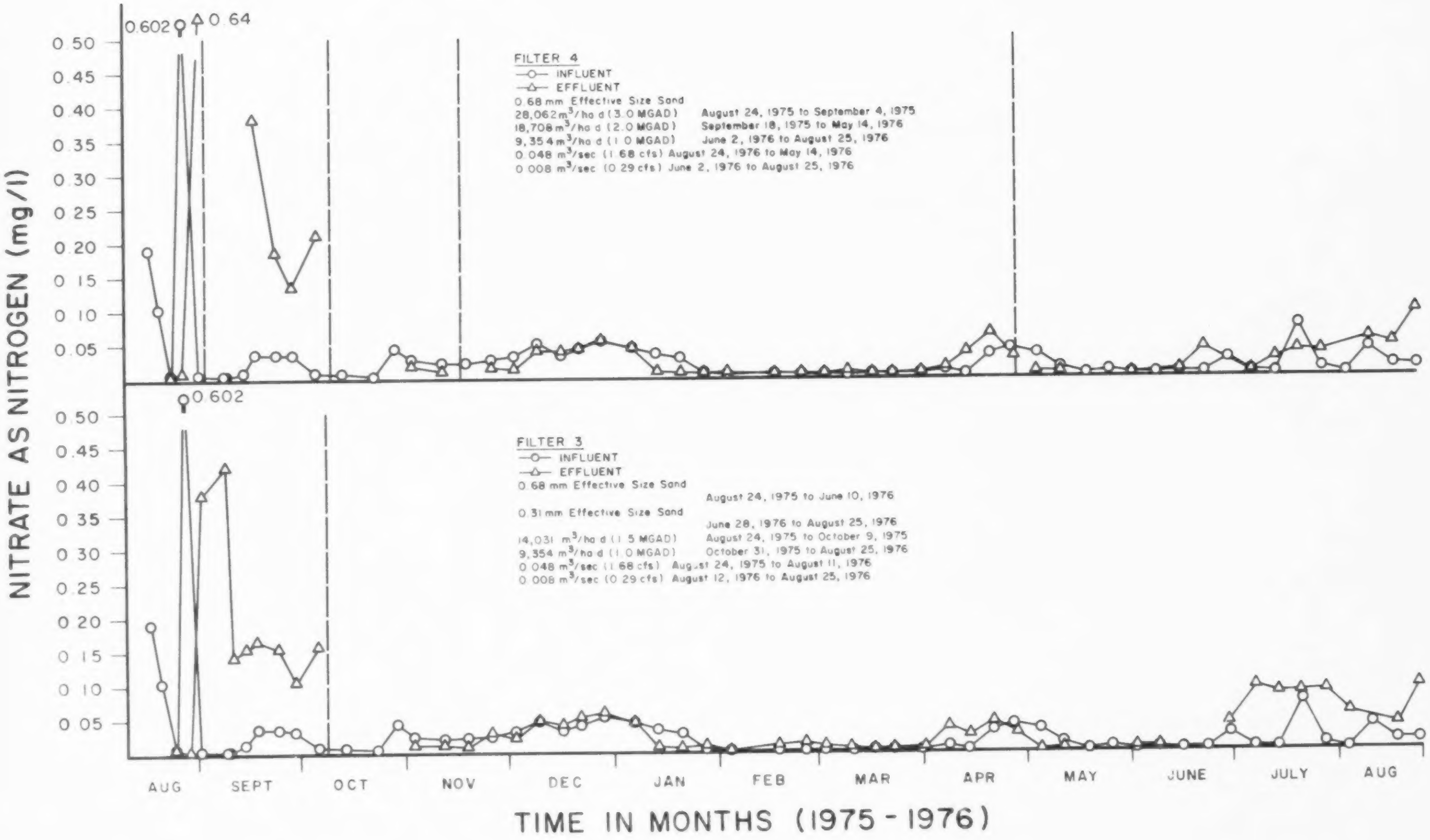

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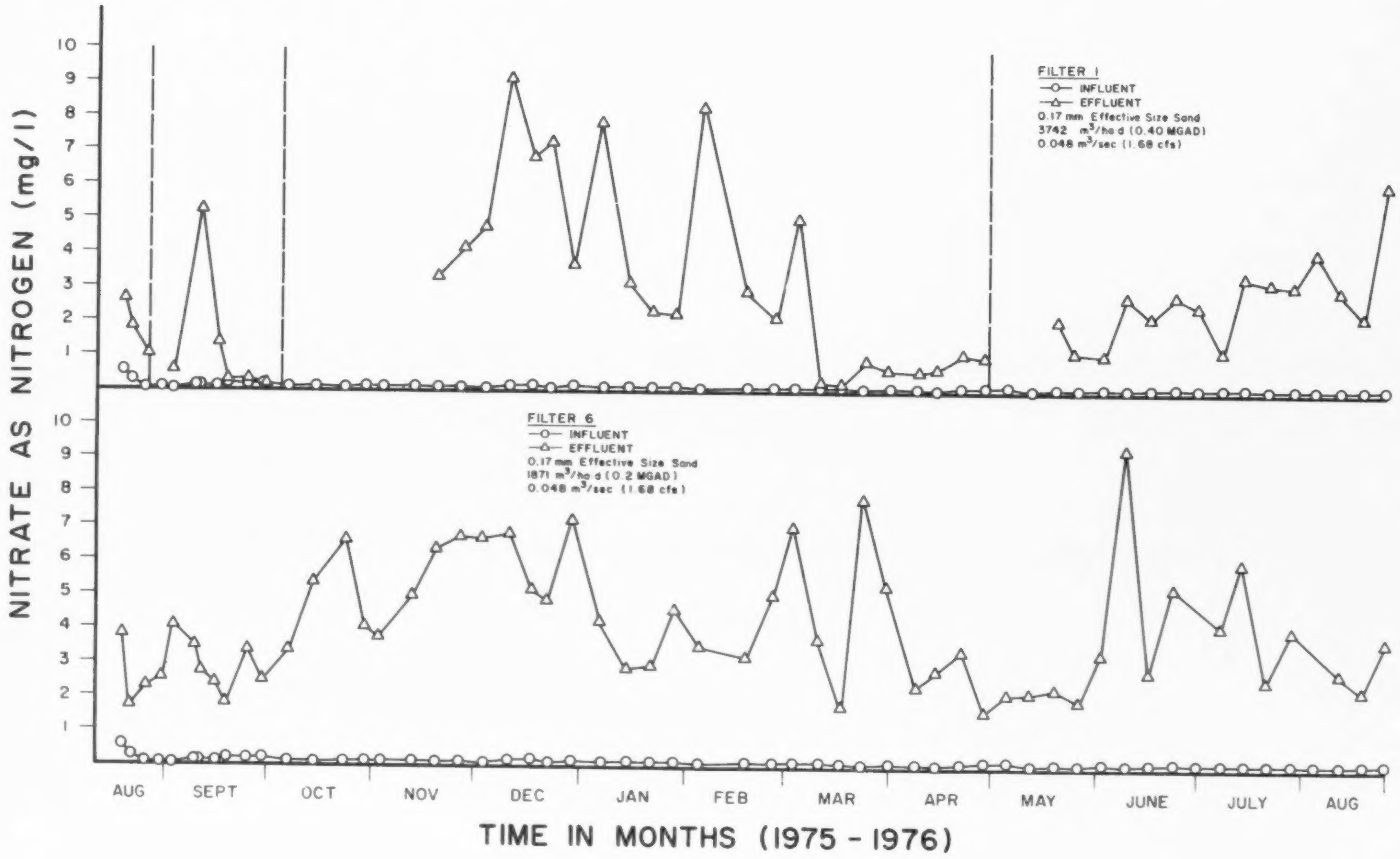

Figure 13. Weekly nitrate-nitrogen performance.

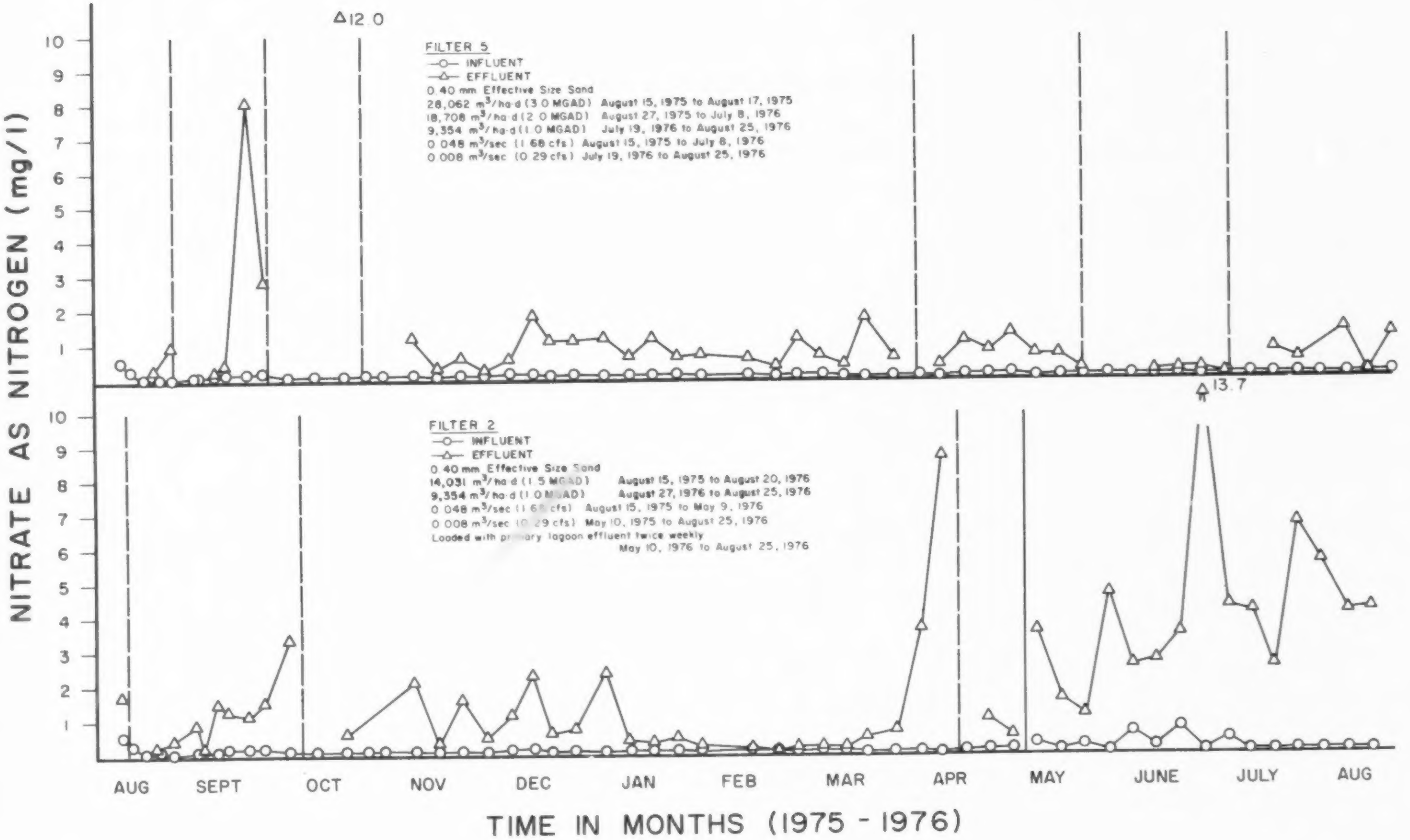

Figure 13. Continued.

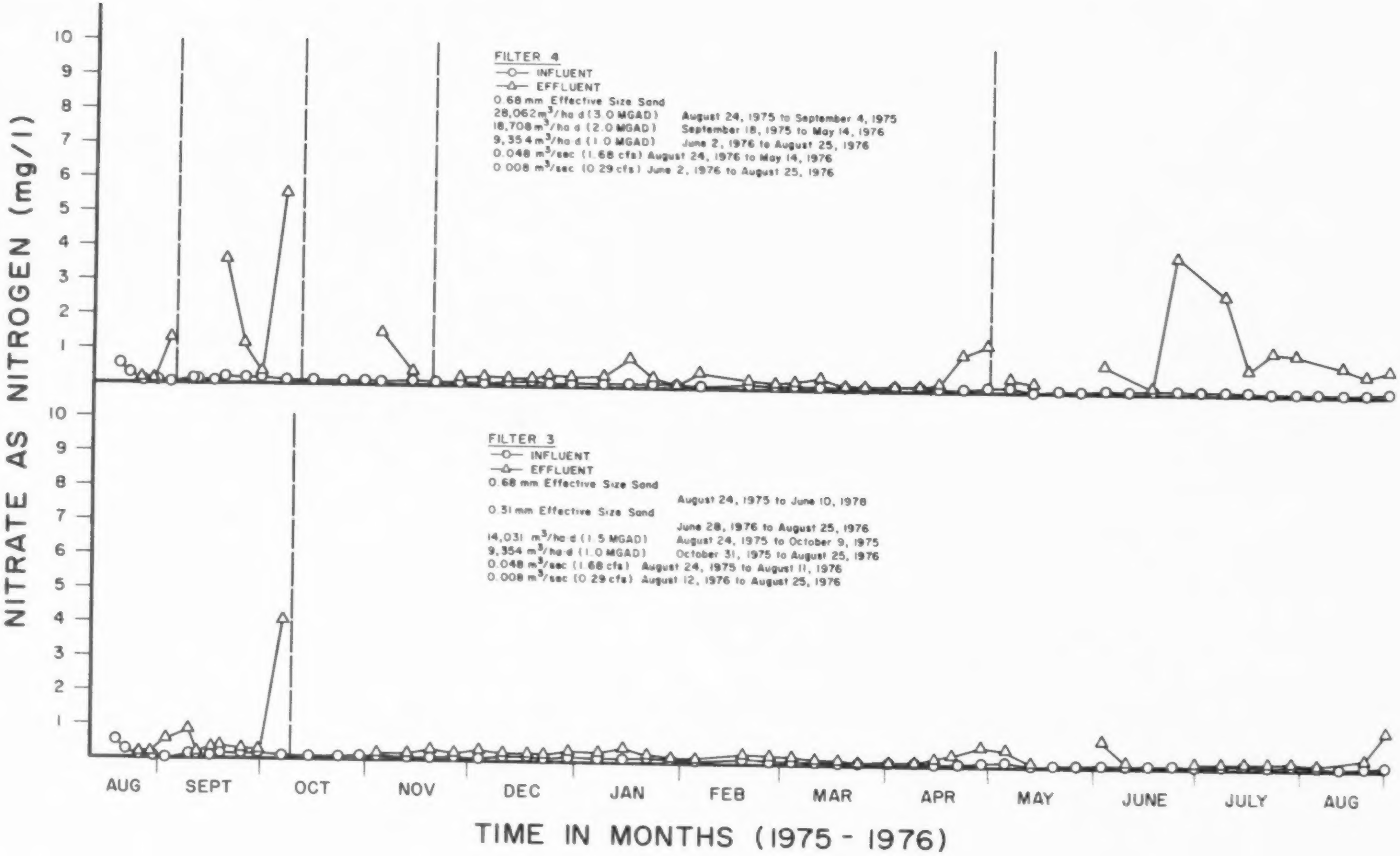

Figure 13. Continued.

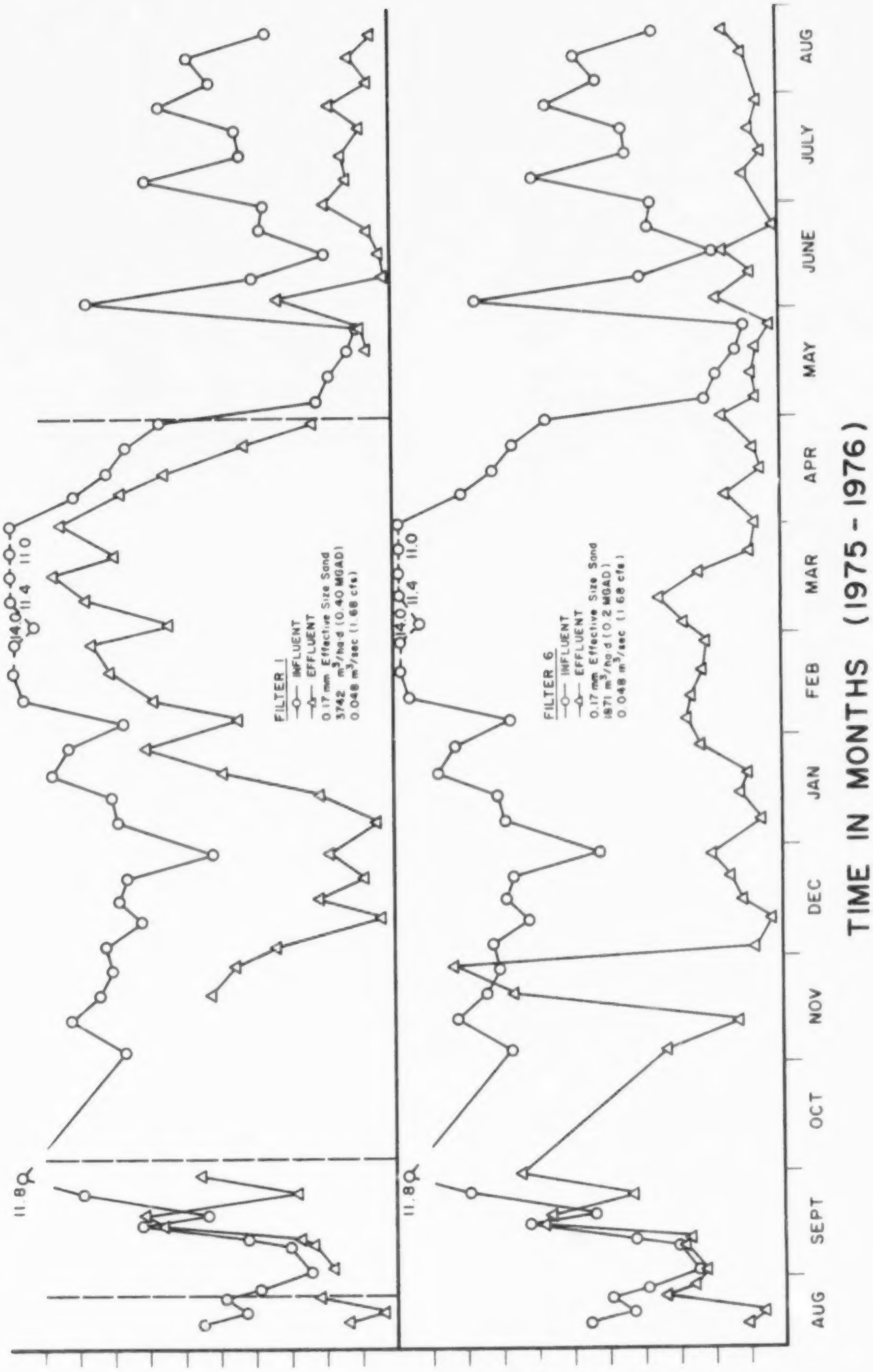

Figure 14. Weekly total Kjeldahl nitrogen performance.

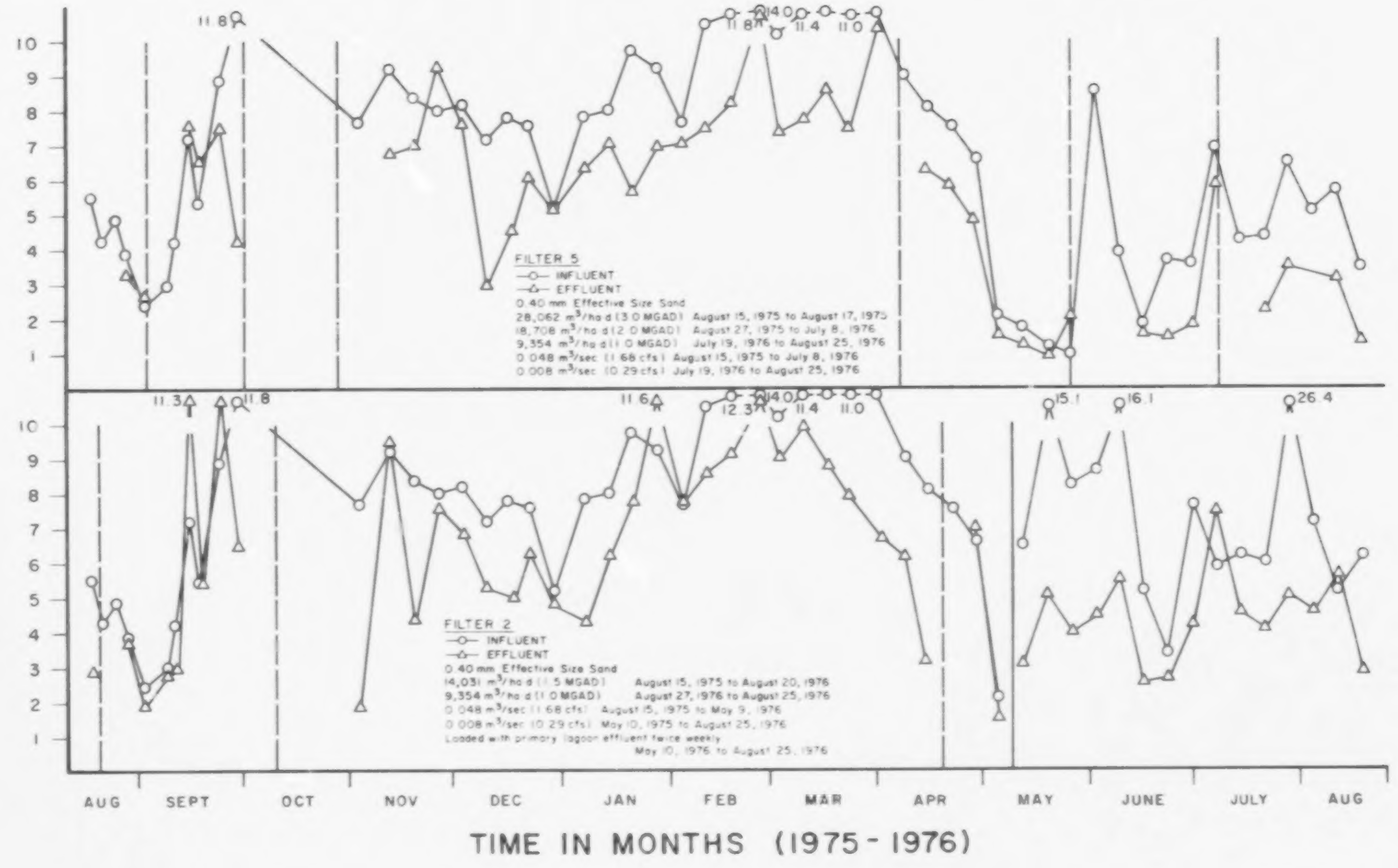

Figure 14. Continued.

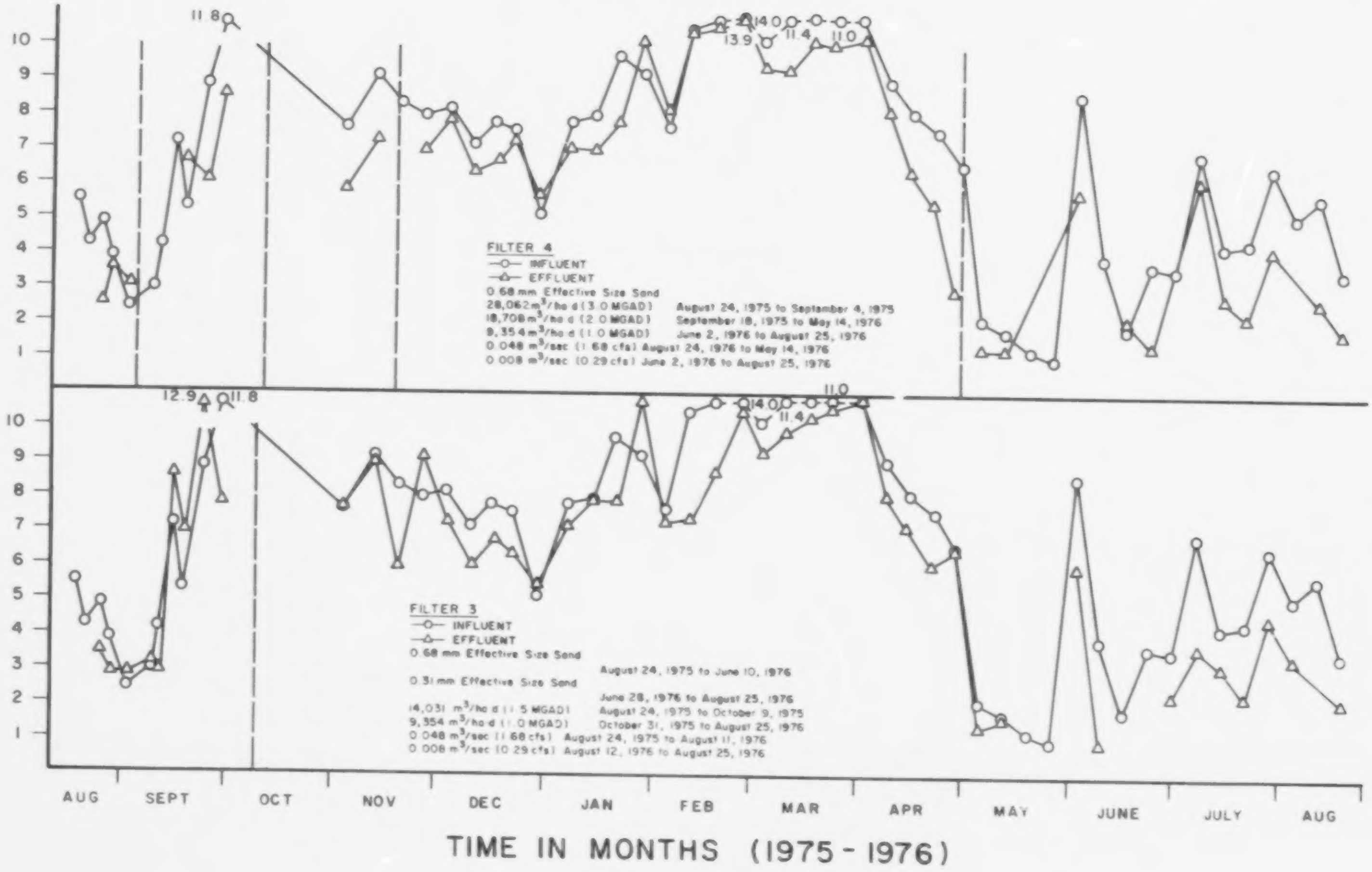

Figure 14. Continued.

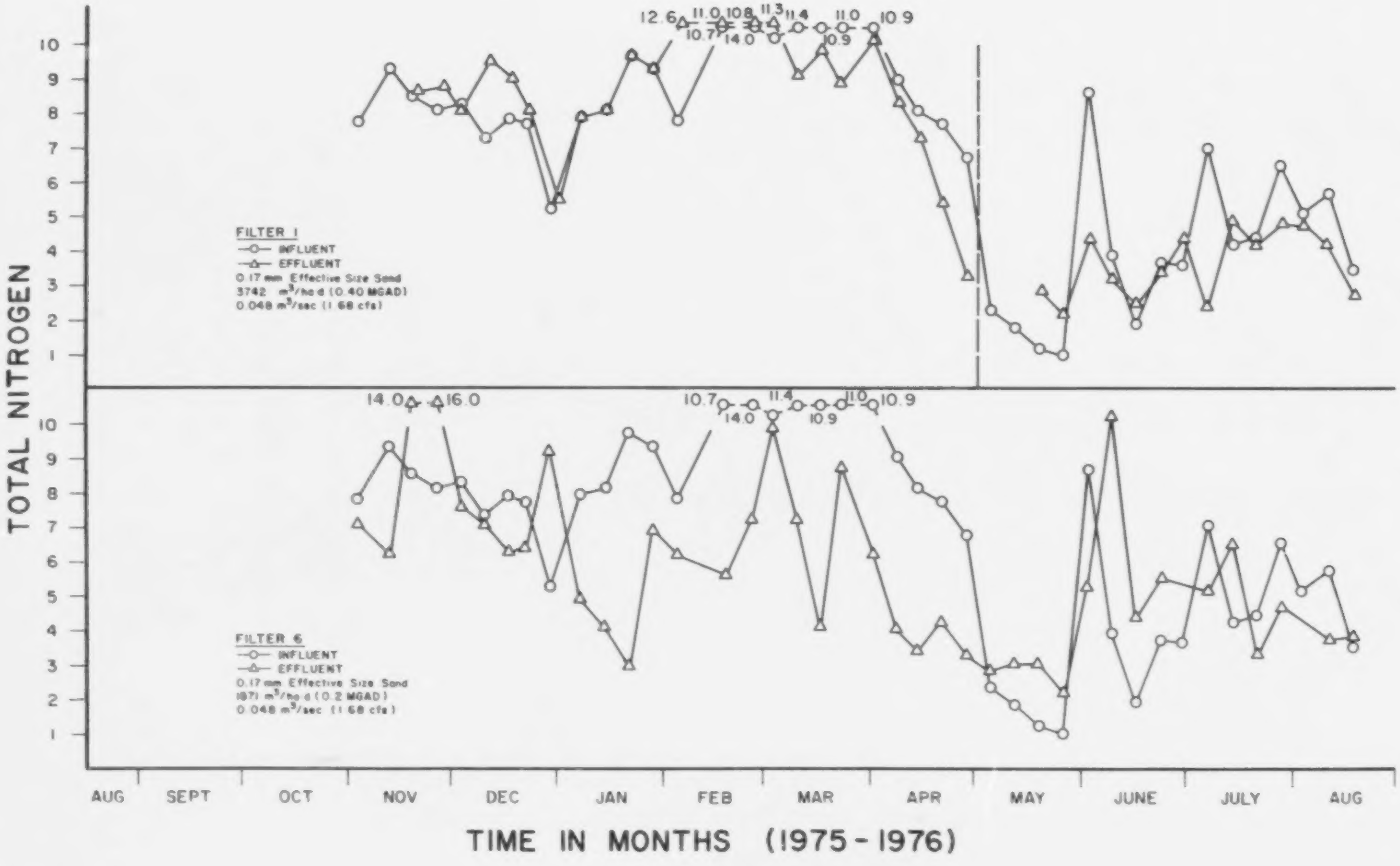

Figure 15. Weekly total nitrogen results.

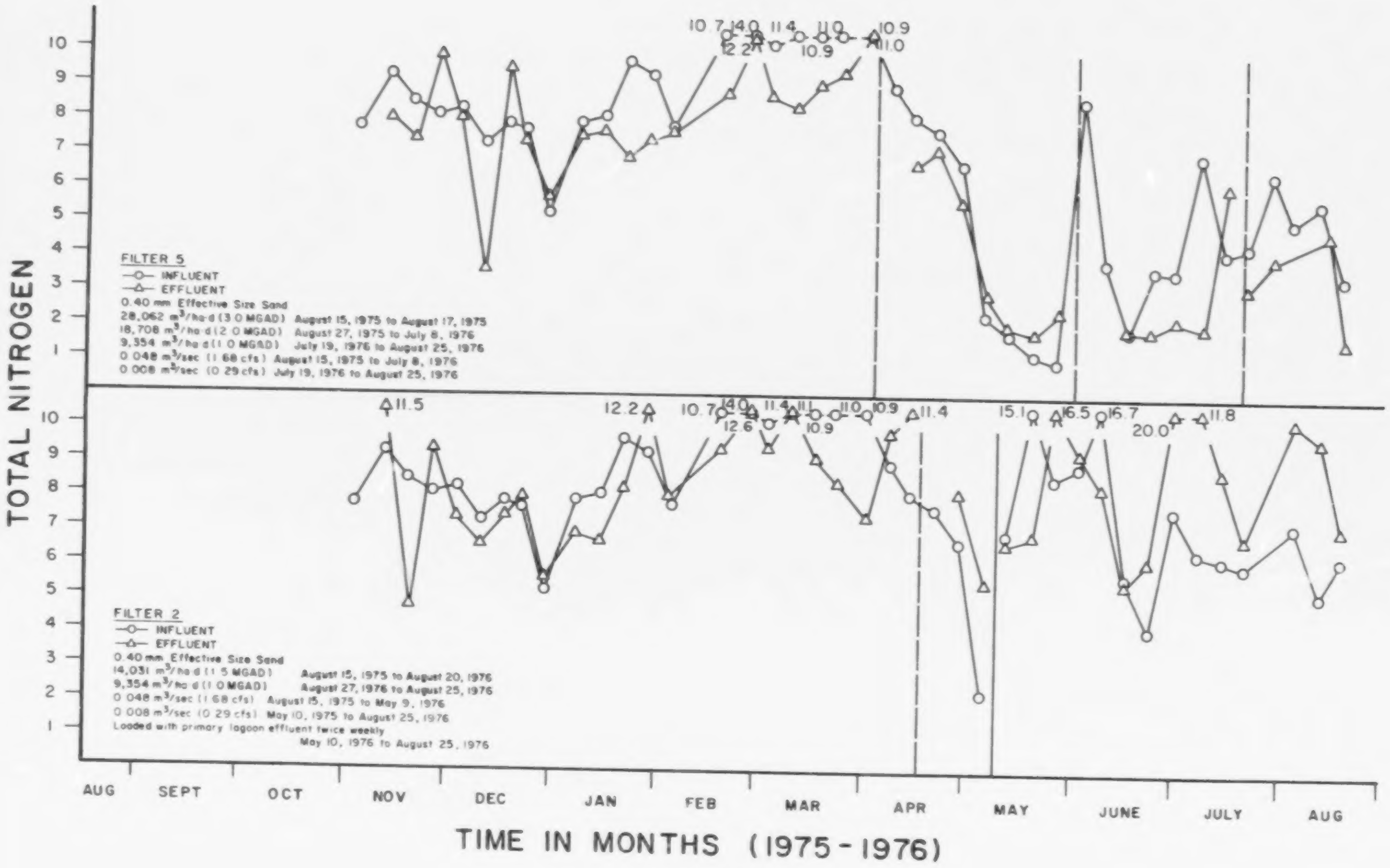

Figure 15. Continued.

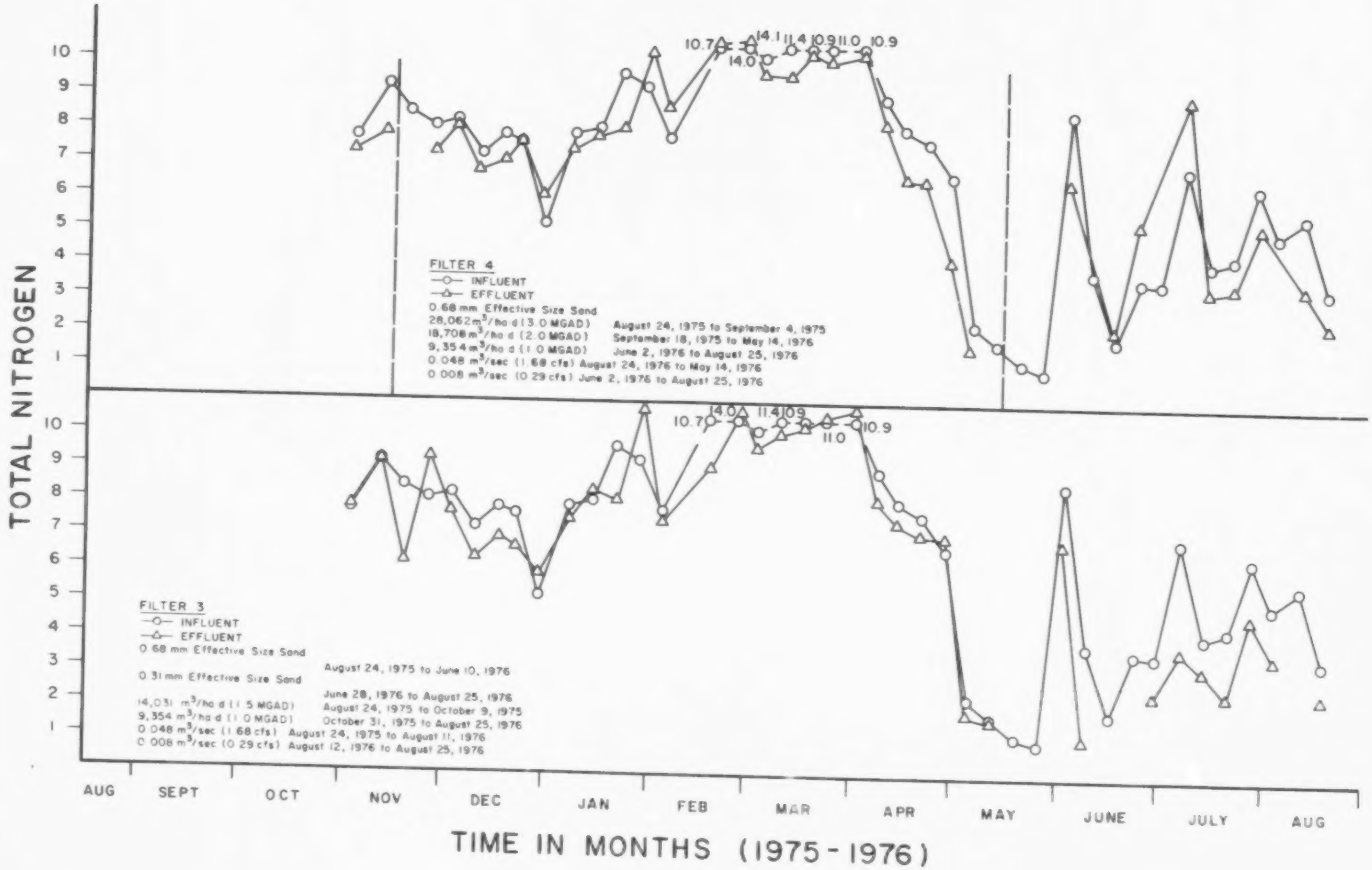

Figure 15. Continued.

Overall, as indicated by Figure 15, about 6 percent of the total nitrogen (TKN, NO_2-N, NO_3-N) was removed.

Summary

The 0.17 mm effective size sand (Filters No. 1 and 6) produced a higher nitrified effluent than the other effective size sands (Filters No. 2, 3, 4, and 5).

Application rate was shown to have a substantial effect on the degree of nitrification with the 0.31 mm, 0.40 mm, and 0.68 mm effective size sands (Filters No. 2, 3, 4, and 5). The lower application rate produced a greater nitrified effluent.

A greater degree of nitrogen oxidation was observed with the finer effective size sands, but nitrogen losses were not affected by the size of sand.

pH AND ALKALINITY

General

Variations in the influent and effluent pH values and alkalinity concentrations for the various effective size sands are reported in Tables 18 and 19 and shown in Figures 16 and 17. Comparison of the influent pH values with the influent alkalinity concentrations indicates a decrease in alkalinity occurs at high pH values (i.e., pH above 9.0). This is typical of lagoon effluent and is a result of calcium carbonate precipitation under high pH conditions caused by algal growth (Sawyer and McCarty, 1967).

In general, the median influent pH values for all the filter runs ranged from 8.3 to 9.1. The corresponding average influent pH values ranged from 8.6 to 9.3 with individual values ranging from 7.7 to 9.8.

Efficiency of 0.68 mm Effective Size Sand

The 0.68 mm effective size sand (Filters No. 3 and 4) with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD) and an application rate of 0.048 m^3/sec (1.68 cfs) did not lower the influent pH value to meet the Federal Secondary Treatment Standards of 6 and 9 consistently. The median effluent pH values for these effective size sands were 8.9 and 8.4, respectively.

Lowering the application rate on the 0.68 mm filter (Filter No. 4) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) to 0.008 m^3/sec (0.29 cfs) reduced the pH value within the Federal Secondary Treatment Standards on 80 percent of the samples. The resulting median effluent pH value was 8.4.

The 0.68 mm effective size sand (Filters No. 3 and 4) operating under various hydraulic loading rates and application rates achieved effluent alkalinity concentrations that followed very closely the influent alkalinity concentrations with a mean decrease of 4 mg/l as $CaCO_3$.

TABLE 18. YEARLY SUMMARY OF THE pH PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent pH			Effluent pH		
			Min.	Max.	Median	Min.	Max.	Median
0.17	1,871	0.048	7.7	9.8	8.6	6.9	8.7	7.9
0.17	3,742	0.048	7.7	9.8	8.6	7.0	8.9	8.0
0.31	9,354	0.048	8.3	9.5	9.1	7.6	9.0	9.1
0.31	9,354	0.008	8.8	8.8	8.8	7.6	7.6	7.7
0.40	9,354	0.048	7.7	9.8	8.3	7.3	11.5	8.2
0.40	9,354	0.008	8.3	9.2	8.8	7.3	9.0	7.8
0.40	14,031	0.048	8.9	8.9	8.9	8.9	8.9	8.9
0.40	18,708	0.048	7.7	9.8	8.6	7.4	9.8	8.5
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	7.7	9.8	8.3	7.7	10.2	8.9
0.68	9,354	0.008	8.6	9.6	9.1	7.4	9.6	8.4
0.68	14,031	0.048	8.3	9.3	9.1	7.8	9.0	8.9
0.68	18,708	0.048	7.7	9.8	8.1	7.7	10.5	8.4
0.68	28,062	0.048	9.1	9.4	9.3	8.0	9.0	8.9
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	8.3	9.3	8.3	8.1	7.1	

N.A. = Not available.

Efficiency of 0.40 mm Effective Size Sand

Federal Secondary Treatment Standards for the pH value were met 50 percent of the time by the effluent from the 0.40 mm effective size sand (Filter No. 5) with a hydraulic loading rate of 18,708 m^3/ha.d (2.0 MGAD).

A significant difference in pH and alkalinity was observed with Filter No. 5 when a wastewater application rate of 0.008 m^3/sec (0.29 cfs) and a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD). The median influent pH value was 8.8 and the median effluent pH value was 8.4. The mean effluent alkalinity concentration increased from 251 to 264 mg/l as $CaCO_3$.

Efficiency of 0.31 mm Effective Size Sand

The median influent pH value of 9.1 was unchanged when wastewater was applied to the 0.31 mm effective size sand (Filter No. 3) receiving a

TABLE 19. YEARLY SUMMARY OF THE ALKALINITY PERFORMANCES

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent Alkalinity (mg/l $CaCO_3$)			Effluent Alkalinity (mg/l $CaCO_3$)		
			Min.	Max.	Ave.	Min.	Max.	Ave.
0.17	1,871	0.048	210	348	286	212	332	271
0.17	3,742	0.048	210	348	287	181	332	271
0.31	9,354	0.048	203	263	243	202	257	231
0.31	9,354	0.008	263	284	270	266	285	270
0.40	9,354	0.048	251	348	307	276	334	302
0.40	9,354	0.008	203	284	251	257	275	264
0.40	14,031	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.40	18,708	0.048	251	348	295	217	346	286
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	251	348	300	221	349	296
0.68	9,354	0.008	203	284	247	223	267	243
0.68	14,031	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	18,708	0.048	251	348	285	217	337	299
0.68	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	262	339	285	232	317	265

N.A. = Not available.

hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) at an application rate of 0.048 (1.68 cfs) even though the mean influent alkalinity concentration decreased from 243 to 231 mg/l $CaCO_3$.

When the application rate was lowered to 0.008 m^3/sec (0.29 cfs), the median alkalinity concentration was 270 mg/l as $CaCO_3$ for both the influent and effluents. The median pH value decreased from 8.8 to 7.8.

Efficiency of 0.17 mm Effective Size Sand

The 0.17 mm effective size sand (Filters No. 1 and 6) produced an effluent pH value that satisfied the Federal Secondary Treatment Standards the entire period of study. The median wastewater pH value decreased from 9.8 to 7.9. The yearly mean alkalinity concentration decreased from 287 to 271 mg/l as $CaCO_3$.

Summary

The 0.68 mm and 0.40 mm effective size sands (Filters No. 2, 3, 4, and 5) with an application rate of 0.048 m^3/sec (1.68 cfs) appear unable to satisfy

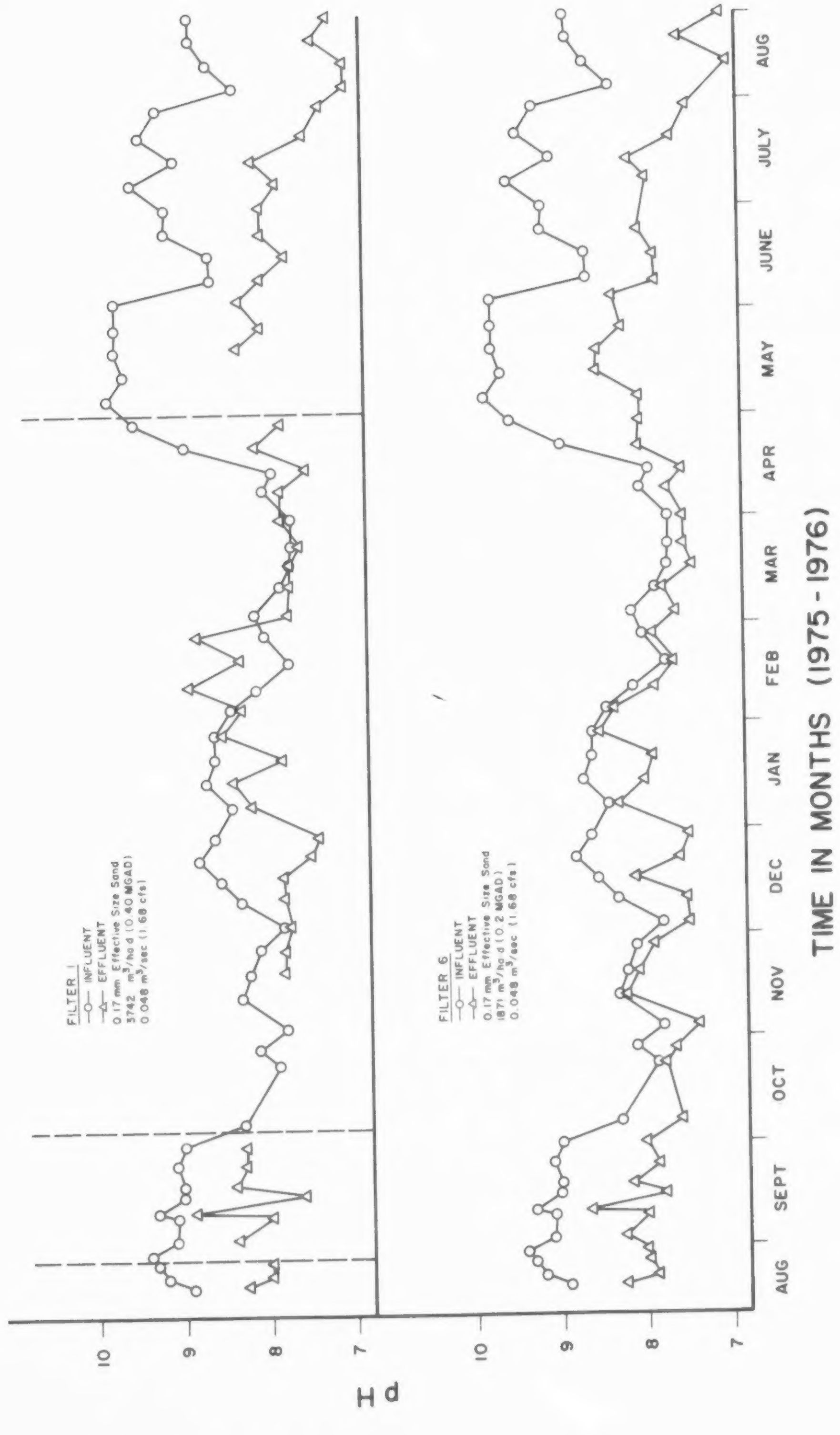

Figure 16. Weekly pH performance.

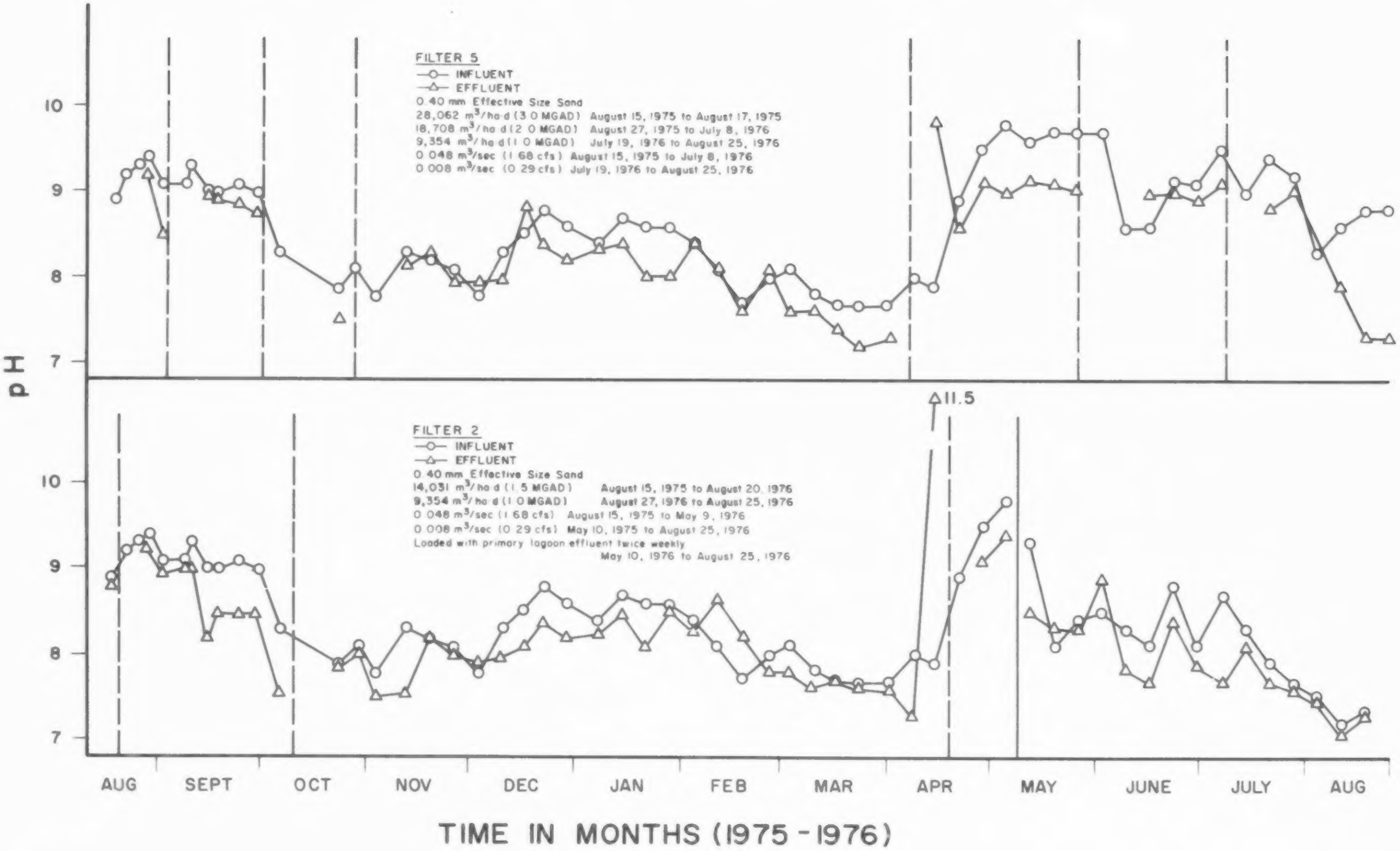

Figure 16. Continued.

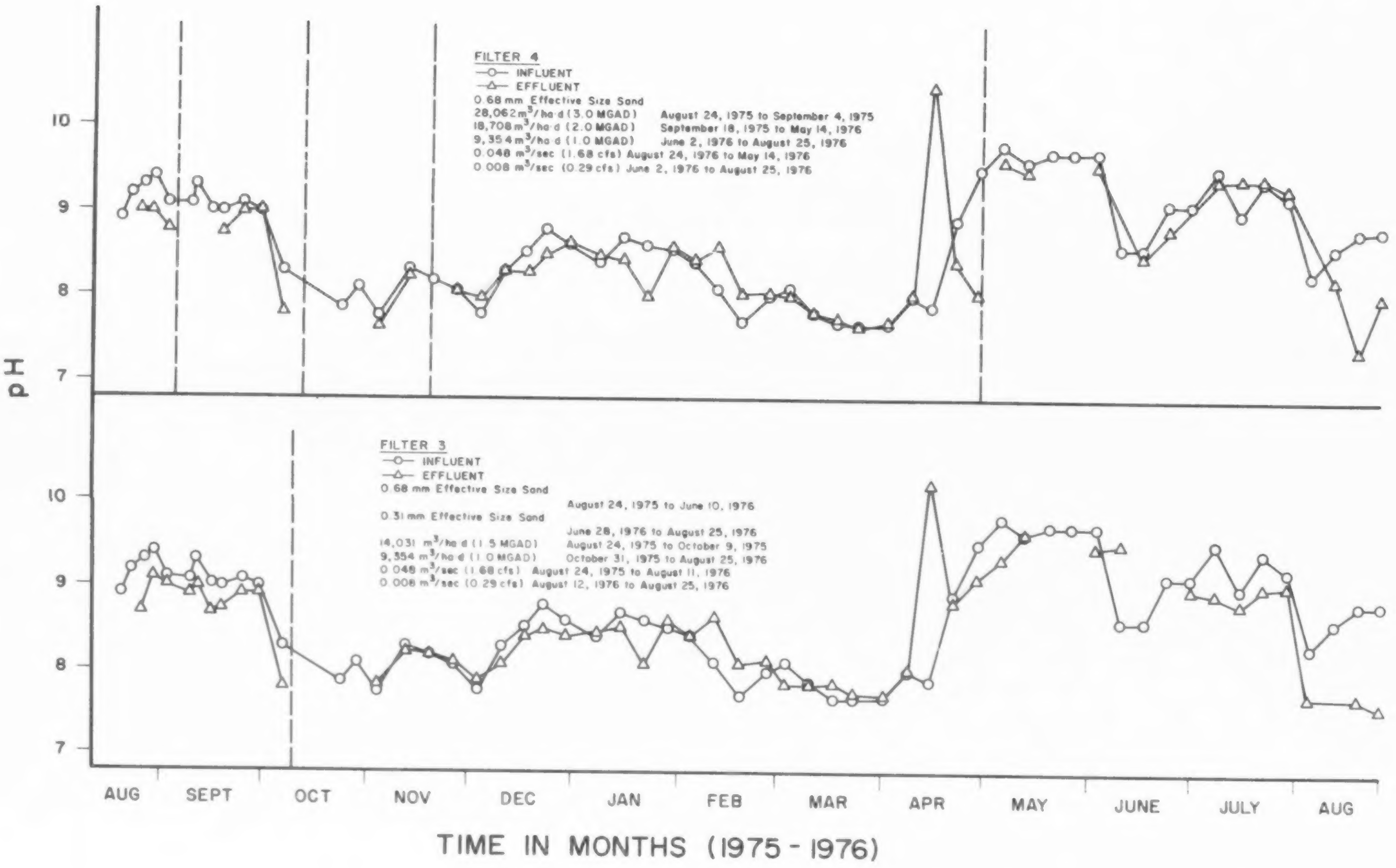

Figure 16. Continued.

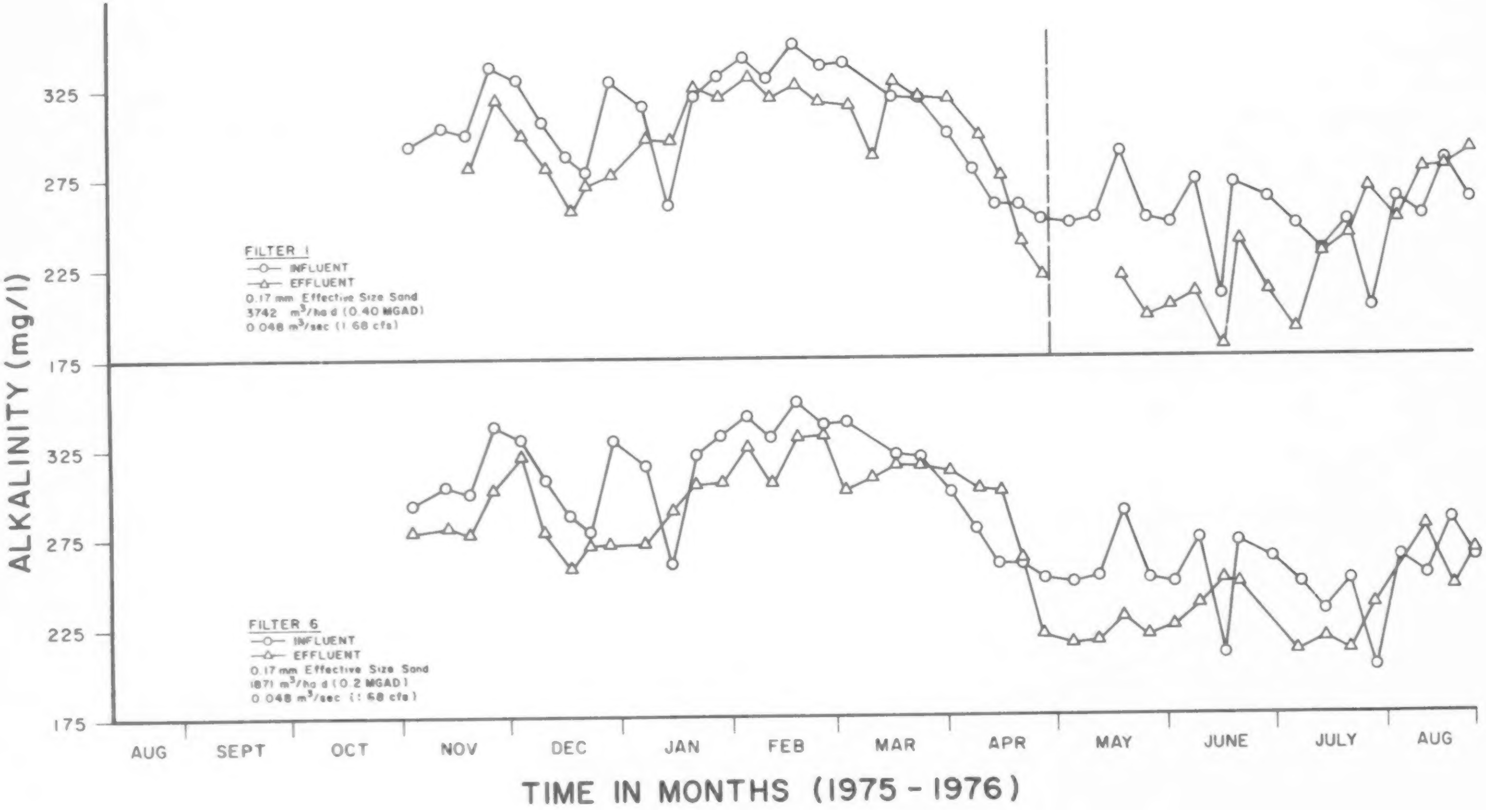

Figure 17. Weekly alkalinity performance.

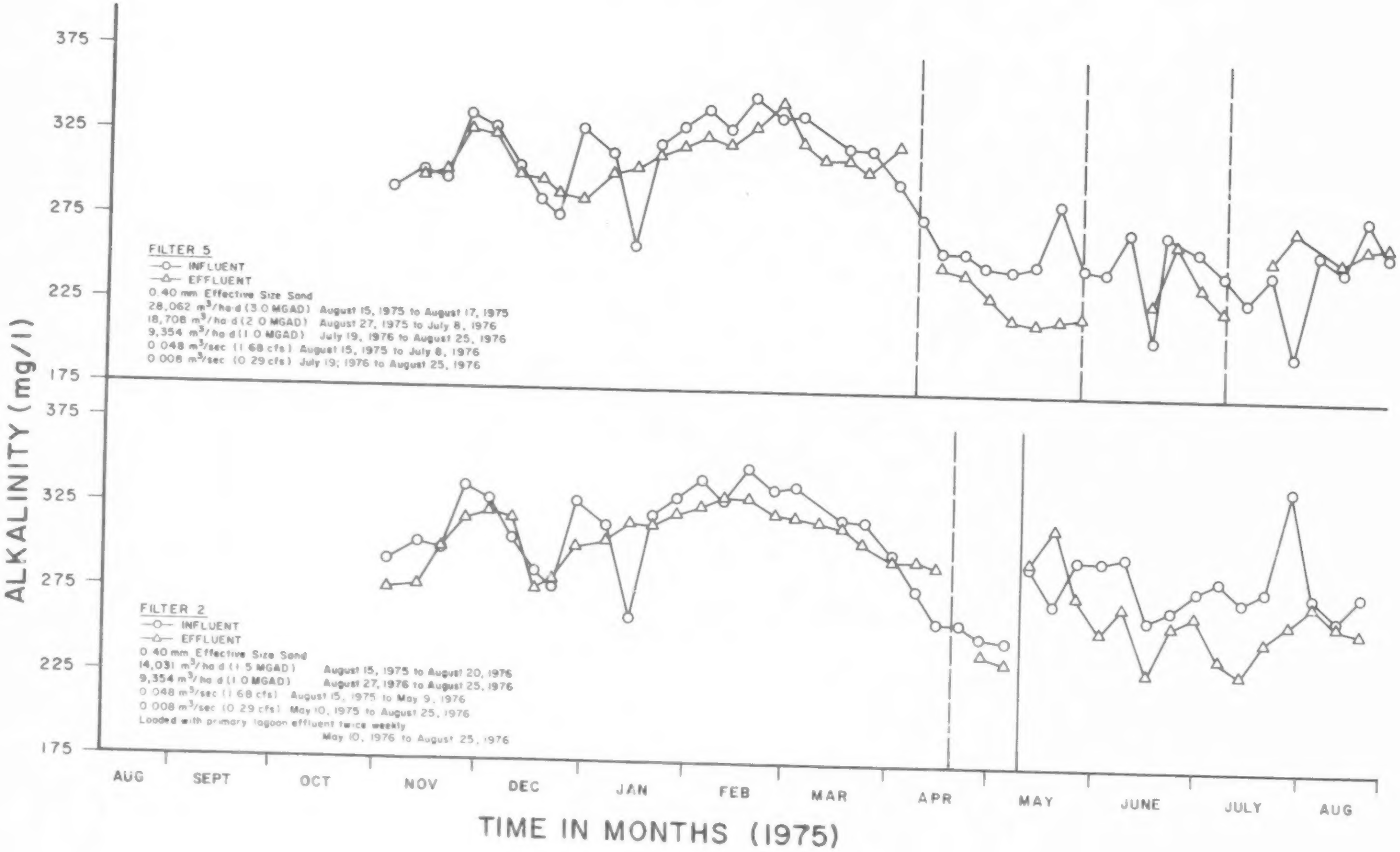

Figure 17. Continued.

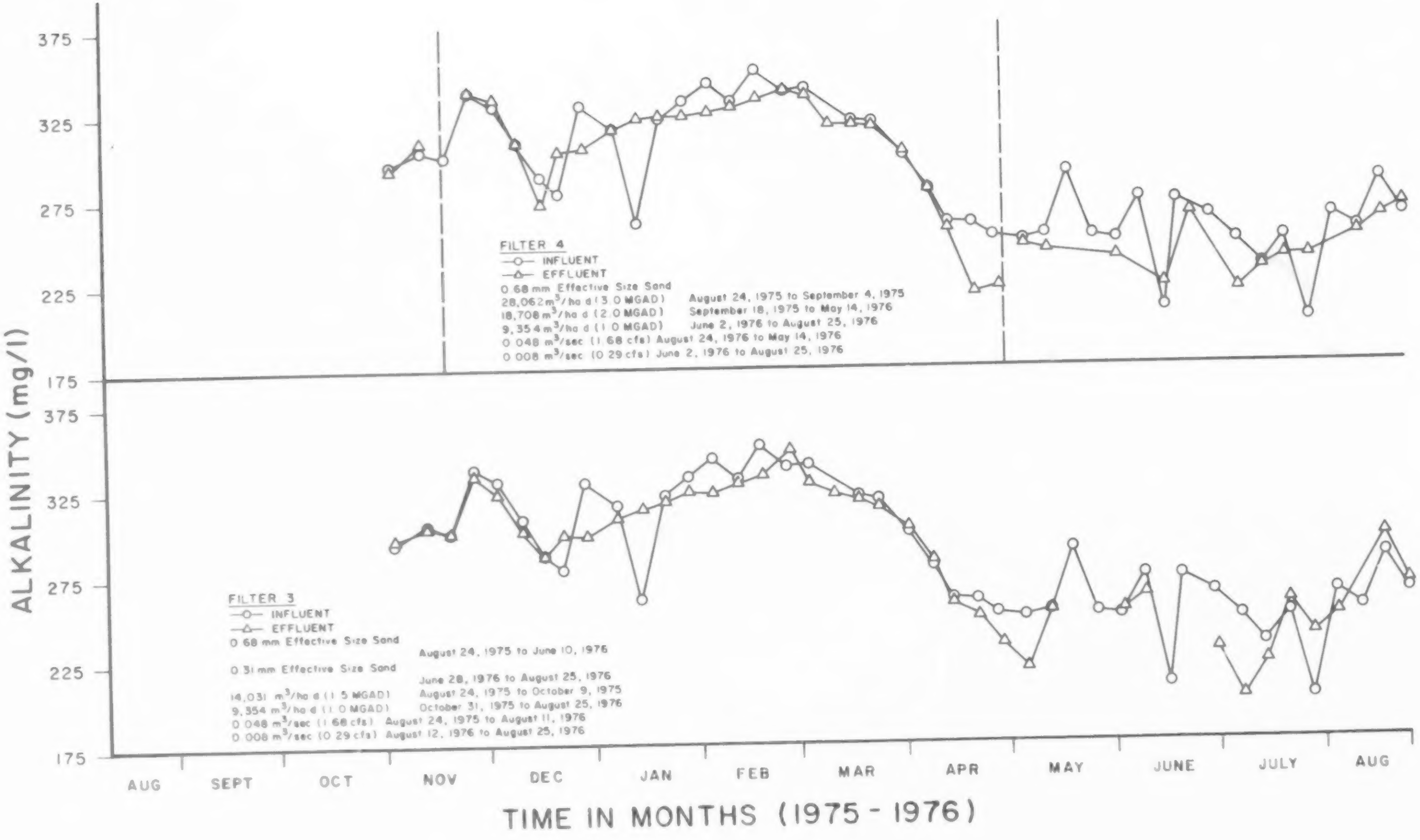

Figure 17. Continued.

the pH standards imposed by the Federal Secondary Treatment Standards. The 0.40 mm effective size sand (Filter No. 5) with a low application rate of 0.008 m^3/sec and the 0.31 mm effective size sand (Filter No. 3) appear capable of satisfying the Federal Secondary Treatment Standards.

An effluent meeting the Federal Secondary Treatment Standards was produced by the 0.17 mm effective size sands (Filters No. 1 and 6) with hydraulic loading rates of 3742 m^3/ha·d (0.4 MGAD) and 1871 m^3/ha·d (0.2 MGAD).

PHOSPHORUS PERFORMANCE

General

Weekly phosphorus concentrations for the filter influent and effluent are shown in Figures 18 and 19. A yearly summary of the phosphorus results are listed in Tables 20 and 21.

Phosphorus removal was indicated during the initial operation of the intermittent sand filters. As operation continued, phosphorus removal became less apparent. Marshall and Middlebrooks (1974) reported that phosphorus removal in intermittent sand filters is a result of ion exchange in the sand. Once the ion exchange sites are saturated with phosphorus, phosphorus removal is no longer obtained.

The mean yearly influent total phosphorus concentration was 2.1 mg/l with individual values ranging from 0.3 to 3.5 mg/l. The mean yearly influent orthophosphate concentration was 1.7 mg/l as phosphorus and individual sample concentrations varied from 0.4 to 3.3 mg/l as phosphorus.

Efficiency of 0.68 mm Effective Size Sand

The 0.68 mm effective size sands (Filters No. 3 and 4) achieved greater than 30 percent influent total phosphorus removal during the first month of operation. However during the remainder of the study, no phosphorus removal was observed. Varying hydraulic loading rates and application rates showed no significant change in phosphorus removal performance.

Efficiency of 0.31 mm and 0.40 mm Effective Sand Size

The 0.40 mm effective size sands (Filters No. 2 and 5) and the 0.31 mm effective size sand (Filter No. 3) resulted in significant phosphorus removal during the initial 15 days of operation, but no significant phosphorus removal was observed during the remaining months of the study. This lack of further phosphorus removal indicates the saturation of the ion exchange sites.

Efficiency of 0.17 mm Effective Size Sand

The 0.17 mm effective size sands (Filters No. 1 and 6) consistently lowered the influent total phosphorus by 8 percent. The mean yearly effluent total phosphorus concentration was 1.9 mg/l. Wastewater orthophosphate concentrations

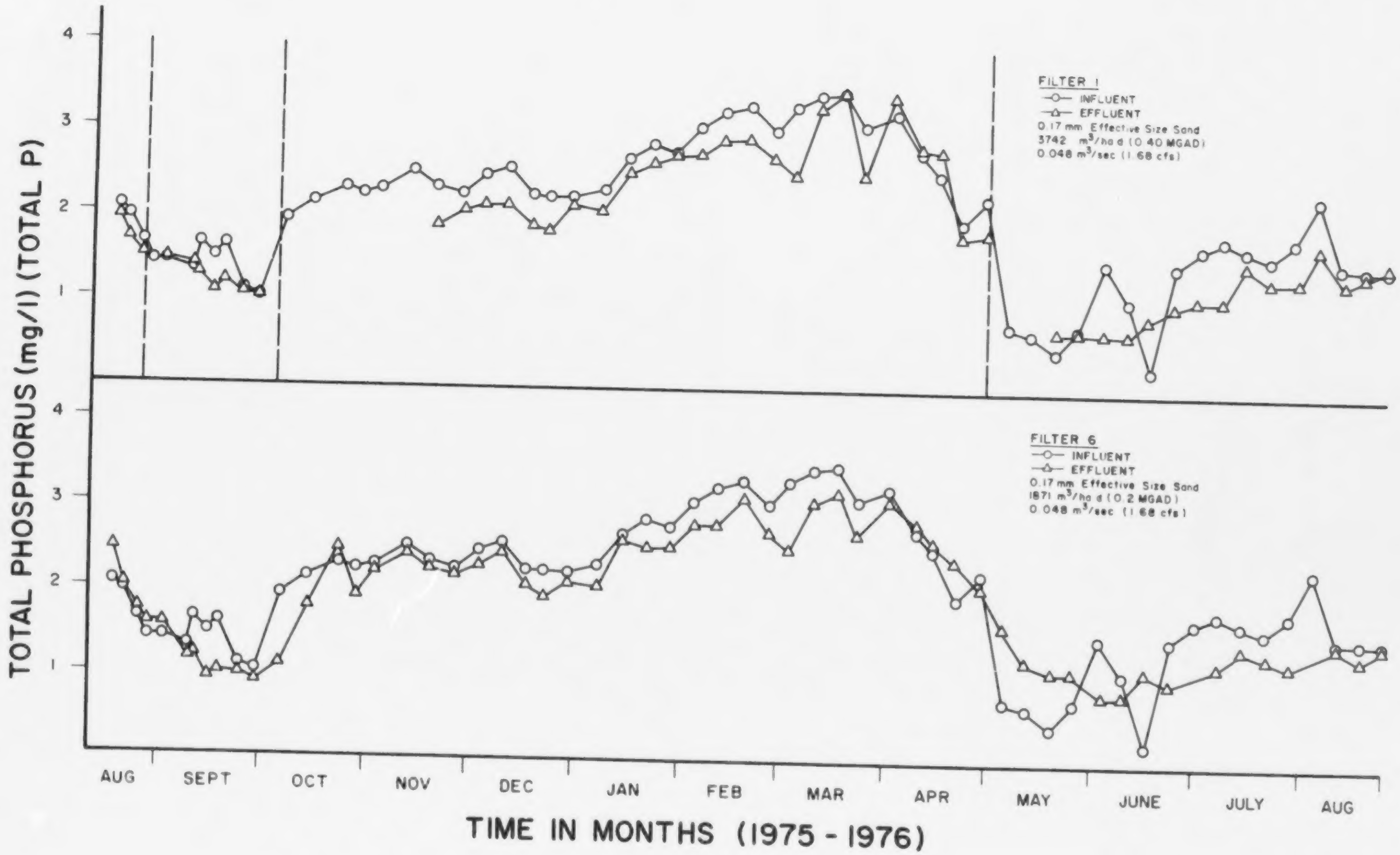

Figure 18. Weekly total phosphorus performance.

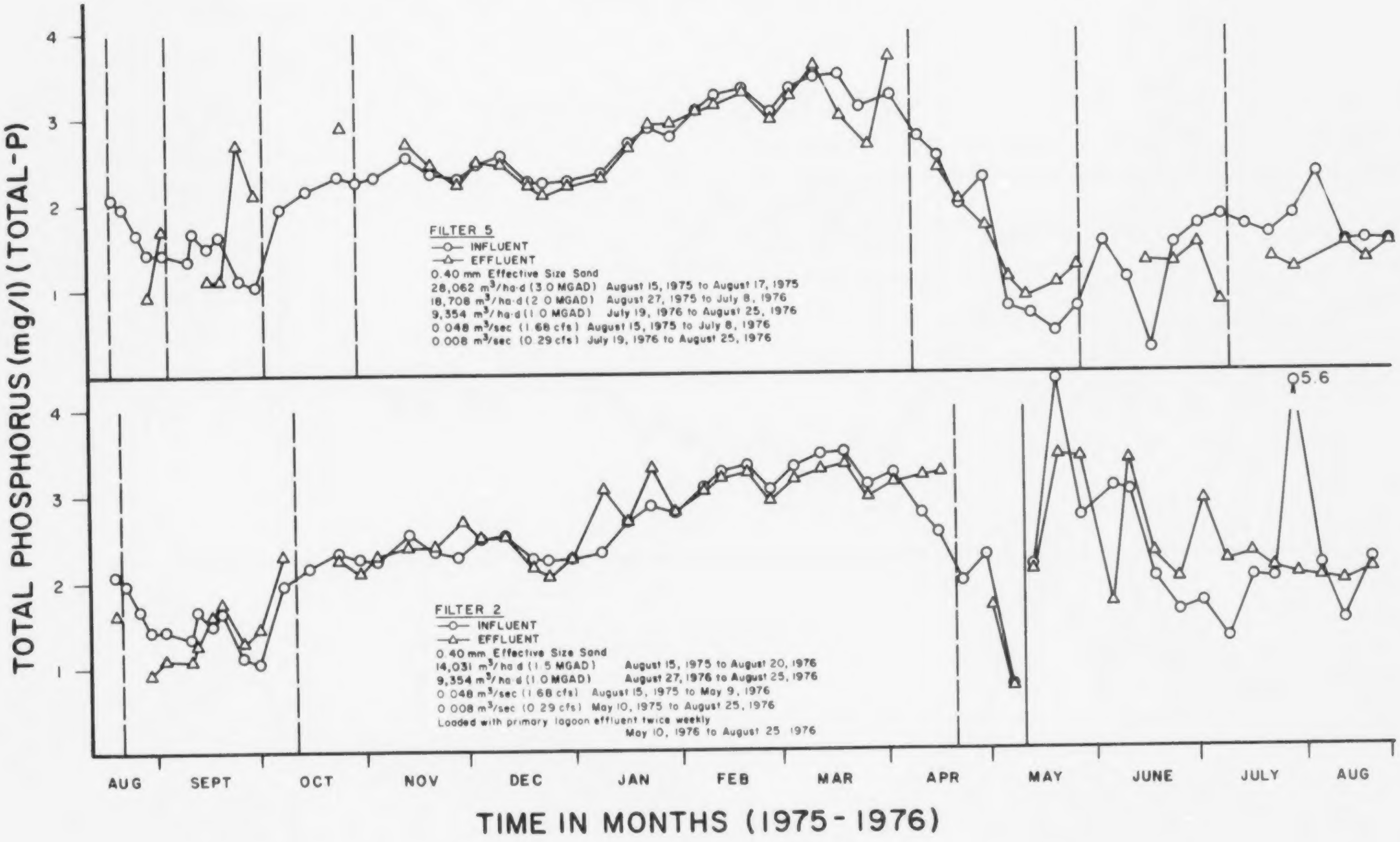

Figure 18. Continued.

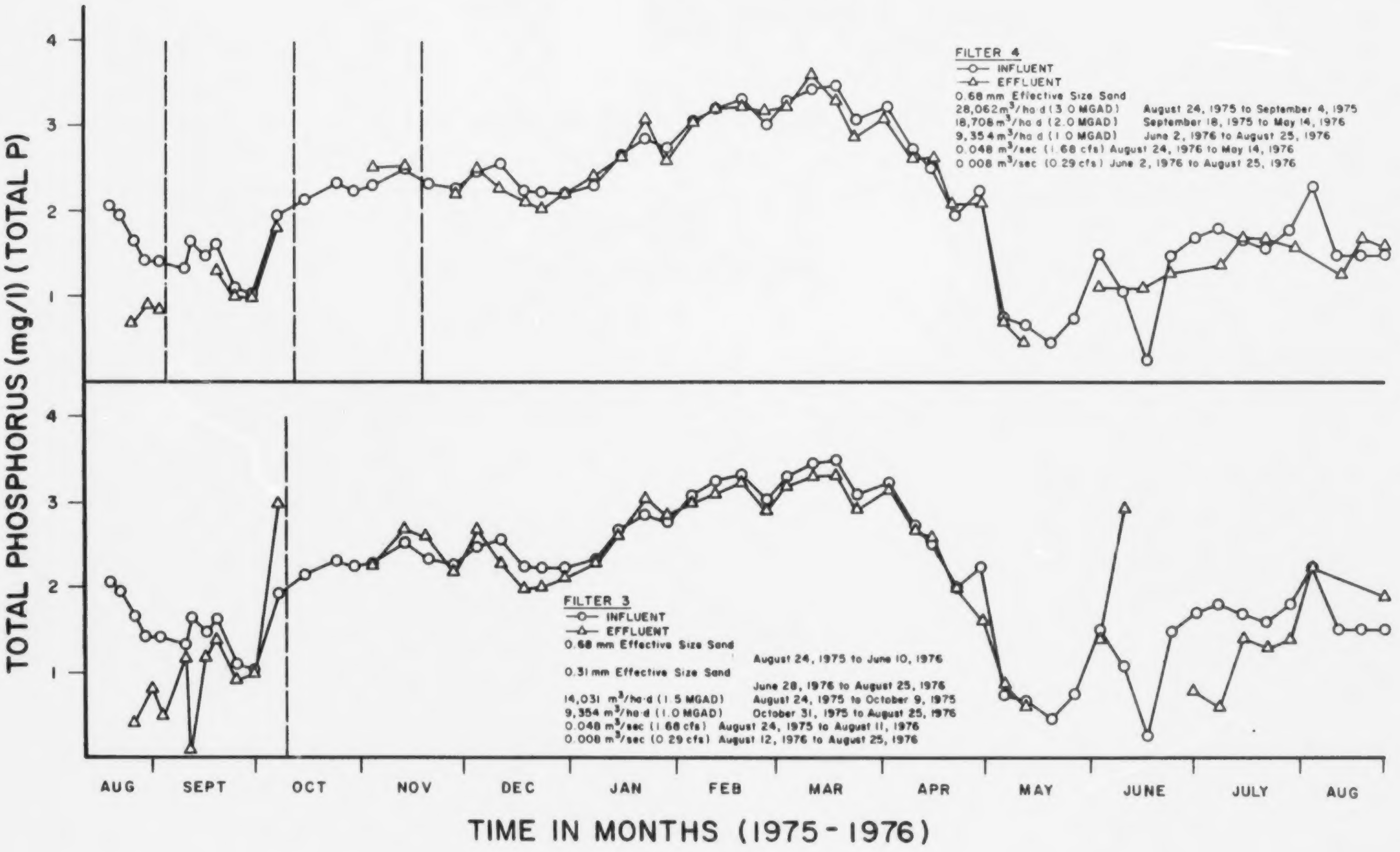

Figure 18. Continued.

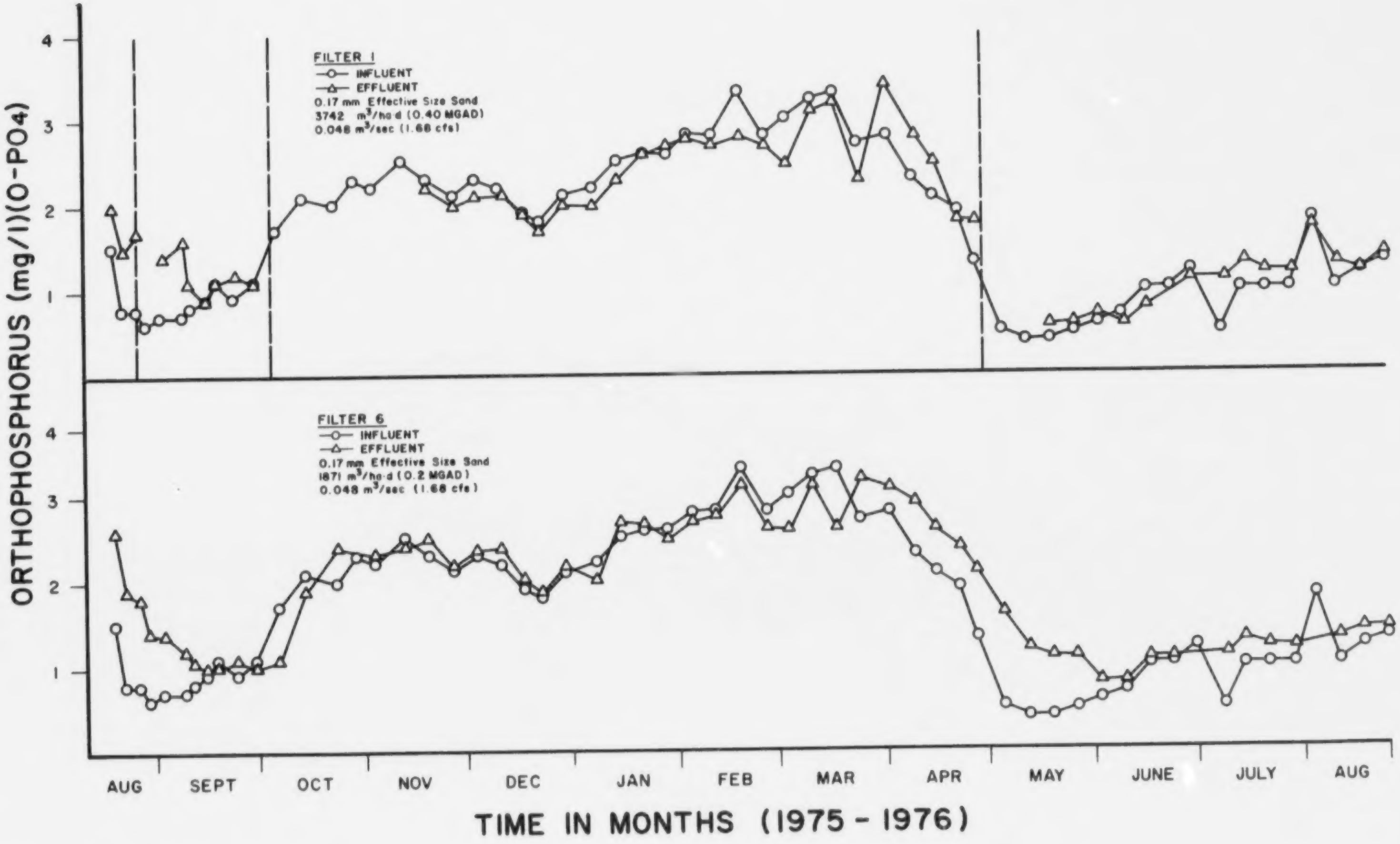

Figure 19. Weekly orthophosphate performance.

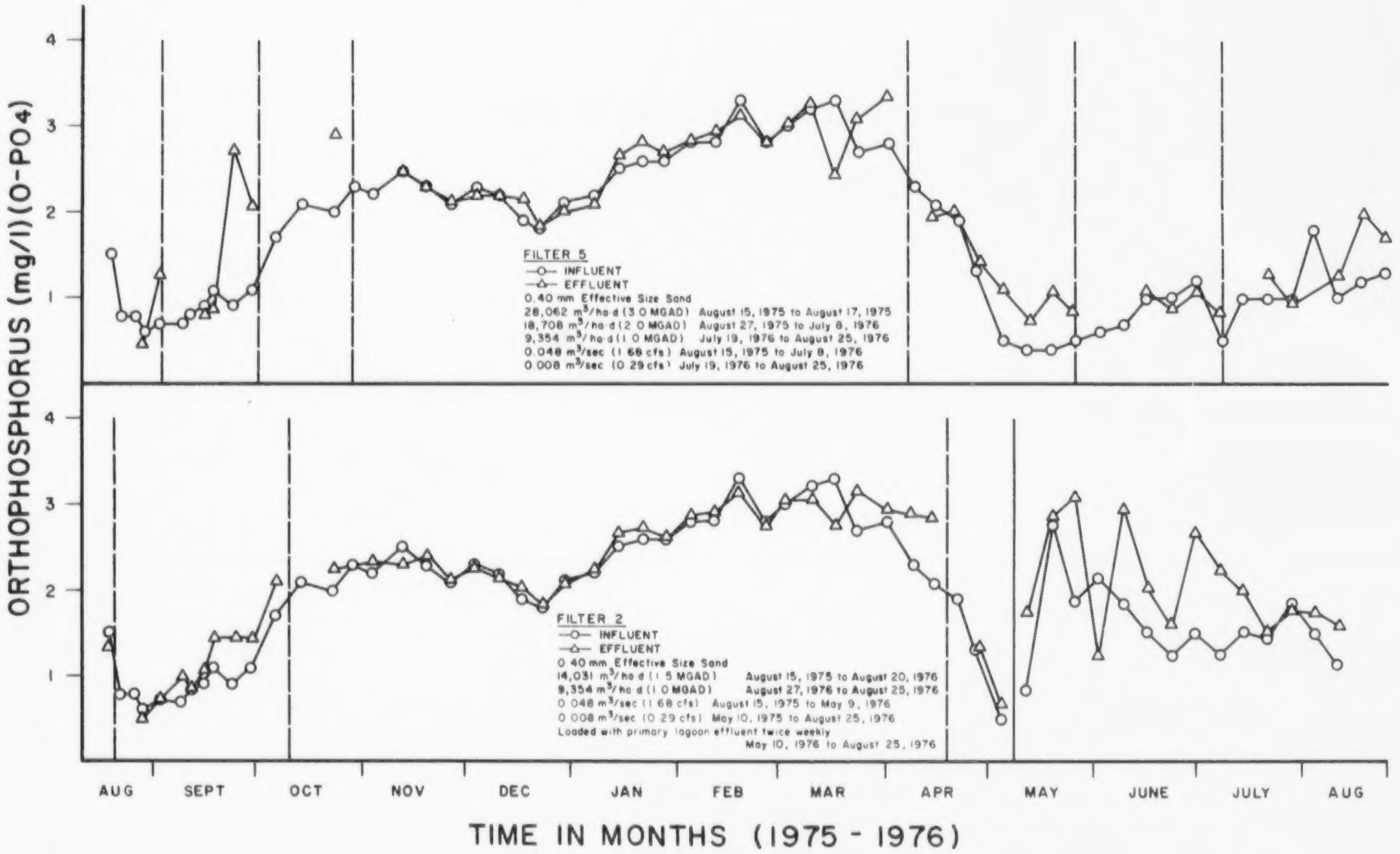

Figure 19. Continued.

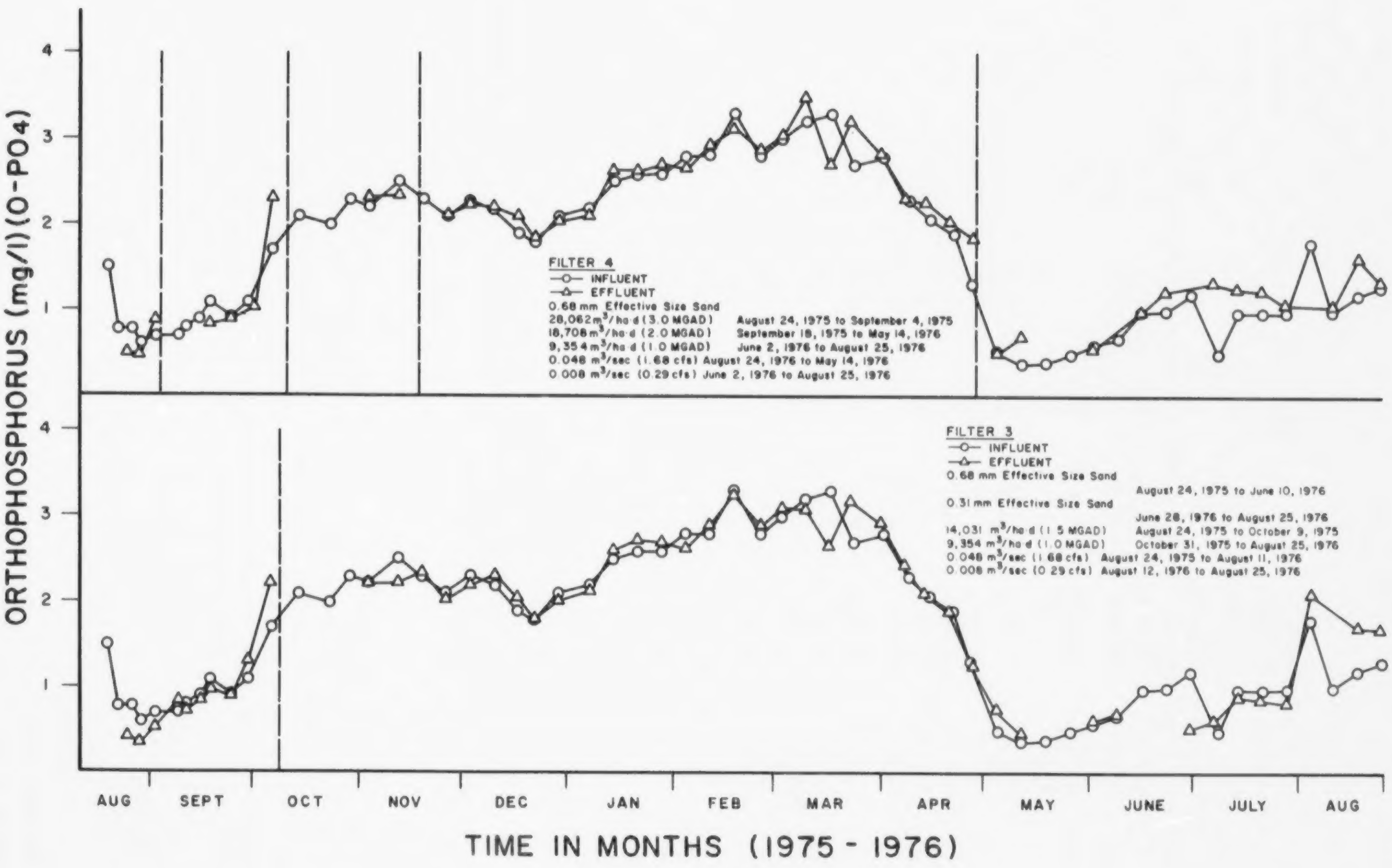

Figure 19. Continued.

TABLE 20. YEARLY SUMMARY OF THE TOTAL PHOSPHORUS PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent Total-P (mg/l)			Effluent Total-P (mg/l)		
			Min.	Max.	Ave.	Min.	Max.	Ave.
0.17	1,871	0.048	0.3	3.5	2.1	0.9	3.2	1.9
0.17	3,742	0.048	0.3	3.5	2.1	0.7	3.5	1.9
0.31	9,354	0.048	1.6	2.3	1.7	0.8	2.3	1.3
0.31	9,354	0.008	1.5	1.5	1.5	1.9	1.9	1.9
0.40	9,354	0.048	0.8	3.5	2.4	0.9	3.4	2.4
0.40	9,354	0.008	1.5	1.8	1.9	1.5	2.1	1.7
0.40	14,031	0.048	2.1	2.1	2.1	1.6	1.6	1.6
0.40	18,708	0.048	0.3	3.5	2.1	0.9	3.7	2.2
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	0.7	3.5	2.5	0.6	3.3	2.5
0.68	9,354	0.008	0.3	1.7	1.5	1.2	2.1	1.5
0.68	14,031	0.048	1.1	2.0	1.5	0.4	3.2	0.9
0.68	18,708	0.048	0.7	3.5	2.4	0.6	3.7	2.4
0.68	28,062	0.048	1.4	1.6	1.2	0.7	0.9	0.8
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	1.5	5.6	2.5	1.9	3.4	2.4

N.A. = Not available.

increased 10 percent throughout the study. The mean yearly orthophosphate concentration was 1.8 mg/l as phosphorus.

Summary

Although initial phosphorus removal by the filters was observed, overall phosphorus removal performance was not significant. Varying hydraulic loading rates and application rates produced little change in filter phosphorus performance. Different effective size sands produced similar effluent phosphorus concentrations. An intermittent sand filter is not recommended for phosphorus removal from lagoon effluent.

DISSOLVED OXYGEN

General

The intermittent sand filters were able to maintain high effluent concentrations of dissolved oxygen (DO) throughout the study. The mean yearly

TABLE 21. YEARLY SUMMARY OF THE ORTHOPHOSPHATE AS PHOSPHORUS PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent O-PO_4 (mg/l)			Effluent O-PO_4 (mg/l)		
			Min.	Max.	Ave.	Min.	Max.	Ave.
0.17	1,871	0.048	0.4	3.3	1.7	0.8	3.2	1.9
0.17	3,742	0.048	0.4	3.3	1.7	0.6	3.3	1.8
0.31	9,354	0.048	0.5	1.8	1.1	0.5	2.1	1.0
0.31	9,354	0.008	1.2	1.3	1.2	1.7	1.8	1.8
0.40	9,354	0.048	0.5	3.3	2.0	0.5	3.2	2.2
0.40	9,354	0.008	1.0	1.8	1.1	1.0	2.0	1.5
0.40	14,031	0.048	1.5	1.5	1.5	1.4	1.4	1.4
0.40	18,708	0.048	0.4	3.3	1.8	0.8	3.4	2.0
0.40	28,062	0.048	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
0.68	9,354	0.048	0.4	3.3	2.2	0.5	3.3	2.2
0.68	9,354	0.008	0.5	1.3	0.9	0.6	1.6	1.3
0.68	14,031	0.048	0.6	1.7	0.8	0.4	2.3	0.8
0.68	18,708	0.048	0.4	3.3	2.2	0.6	3.6	2.3
0.68	28,062	0.048	0.6	0.8	0.7	0.5	0.9	0.6
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	0.8	2.8	1.6	1.3	2.7	2.1

N.A. = Not available.

influent DO was 8.5 mg/l and daily concentrations varied from 0.4 to 19.8 mg/l. An ice layer was formed on the lagoons in November, 1975, and continued into March 1976. The ice layer prevented oxygen transfer from the atmosphere to the lagoon waters, causing low influent DO concentrations during December, 1975, January, February, and March of 1976.

The high influent DO concentrations in April 1976 were caused by heavy algal growth in the lagoon system during April 1976.

The intermittent sand filter dissolved oxygen performance is shown in Table 22 and Figure 20.

Efficiency of 0.68 mm Effective Size Sand

The 0.68 mm effective size sands (Filters No. 3 and 4) with a high application rate of 0.048 m^3/sec (1.68 cfs) and various hydraulic loading rates produced an effluent DO greater than 7 mg/l more than 90 percent of the study. The mean yearly influent DO was 8.5 mg/l and the mean yearly effluent DO was near 9.5 mg/l.

TABLE 22. YEARLY SUMMARY OF THE DISSOLVED OXYGEN PERFORMANCE

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Influent DO (mg/l)			Effluent DO (mg/l)		
			Min.	Max.	Ave.	Min.	Max.	Ave.
0.17	1,871	0.048	0.4	19.8	8.5	5.4	12.4	8.3
0.17	3,742	0.048	0.4	19.8	8.5	4.2	10.4	7.1
0.31	9,354	0.048	2.3	10.3	9.0	5.7	9.0	6.9
0.31	9,354	0.008	8.7	8.7	8.7	7.9	7.9	7.9
0.40	9,354	0.048	0.4	19.8	7.4	5.5	13.4	9.1
0.40	9,354	0.008	4.0	9.8	8.1	4.0	6.4	5.5
0.40	14,031	0.048	8.1	9.8	9.0	7.1	7.3	7.2
0.40	18,708	0.048	0.4	19.8	8.3	2.9	15.0	8.4
0.40	28,062	0.048	9.8	9.8	9.8	7.3	7.3	7.3
0.68	9,354	0.048	0.4	19.8	7.0	7.6	13.0	9.8
0.68	9,354	0.008	4.0	19.4	9.8	1.4	8.0	6.2
0.68	14,031	0.048	1.9	18.0	11.9	6.9	9.2	8.0
0.68	18,708	0.048	0.4	19.8	7.2	3.5	14.3	9.5
0.68	28,062	0.048	9.3	14.9	12.4	4.9	7.5	6.5
Loaded With Primary Lagoon Effluent Twice Weekly								
0.40	9,354	0.008	3.4	11.2	7.2	2.7	9.4	6.8

Lowering the application rate to 0.008 m^3/sec (0.29 cfs) produced an effluent DO greater than 7 mg/l during more than 66 percent of the study. The monthly mean influent DO was 9.8 mg/l and the monthly mean effluent DO was 6.2 mg/l.

Efficiency of 0.40 mm Effective Size Sand

The 0.40 mm effective size sands (Filters No. 2 and 5) with various hydraulic loading rates and an application rate of 0.048 m^3/sec (1.68 cfs) achieved an effluent DO concentration greater than 7 mg/l during 20 percent of the study. The mean influent DO was 7.8 mg/l and the mean effluent DO was 8.7 mg/l. Operation under the low application rate of 0.008 m^3/sec (0.29 cfs) resulted in an effluent DO concentration less than 7 mg/l during the entire study.

Filter plugging was preceded by a decrease in effluent DO concentration when the 0.40 mm effective size sand (Filter No. 5) was operated at a hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD) and an application rate of 0.048 m^3/sec (1.68 cfs). This may indicate the lack of oxygen circulation in the filter bed once the filter surface pores are clogged.

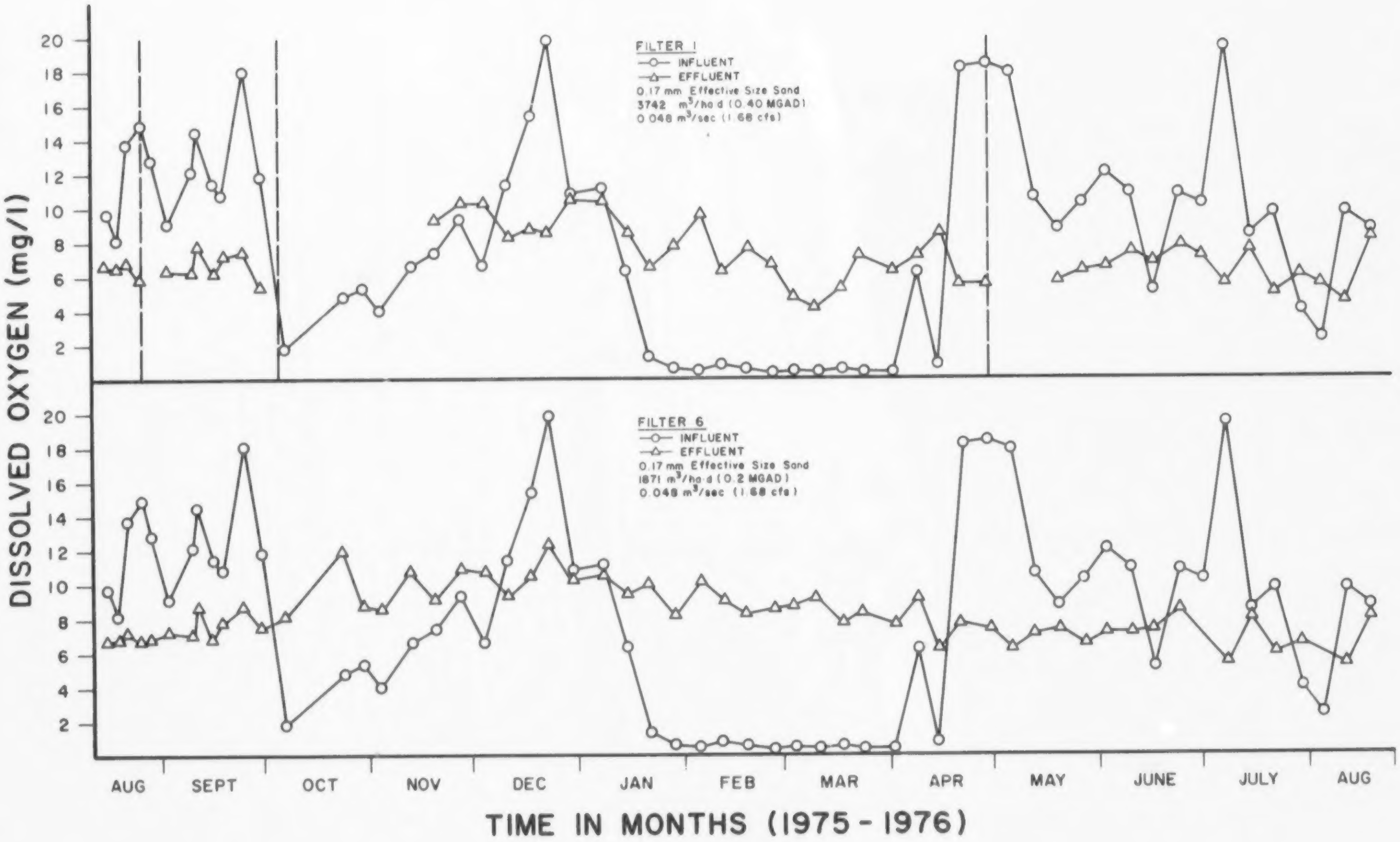

Figure 20. Weekly dissolved oxygen performance.

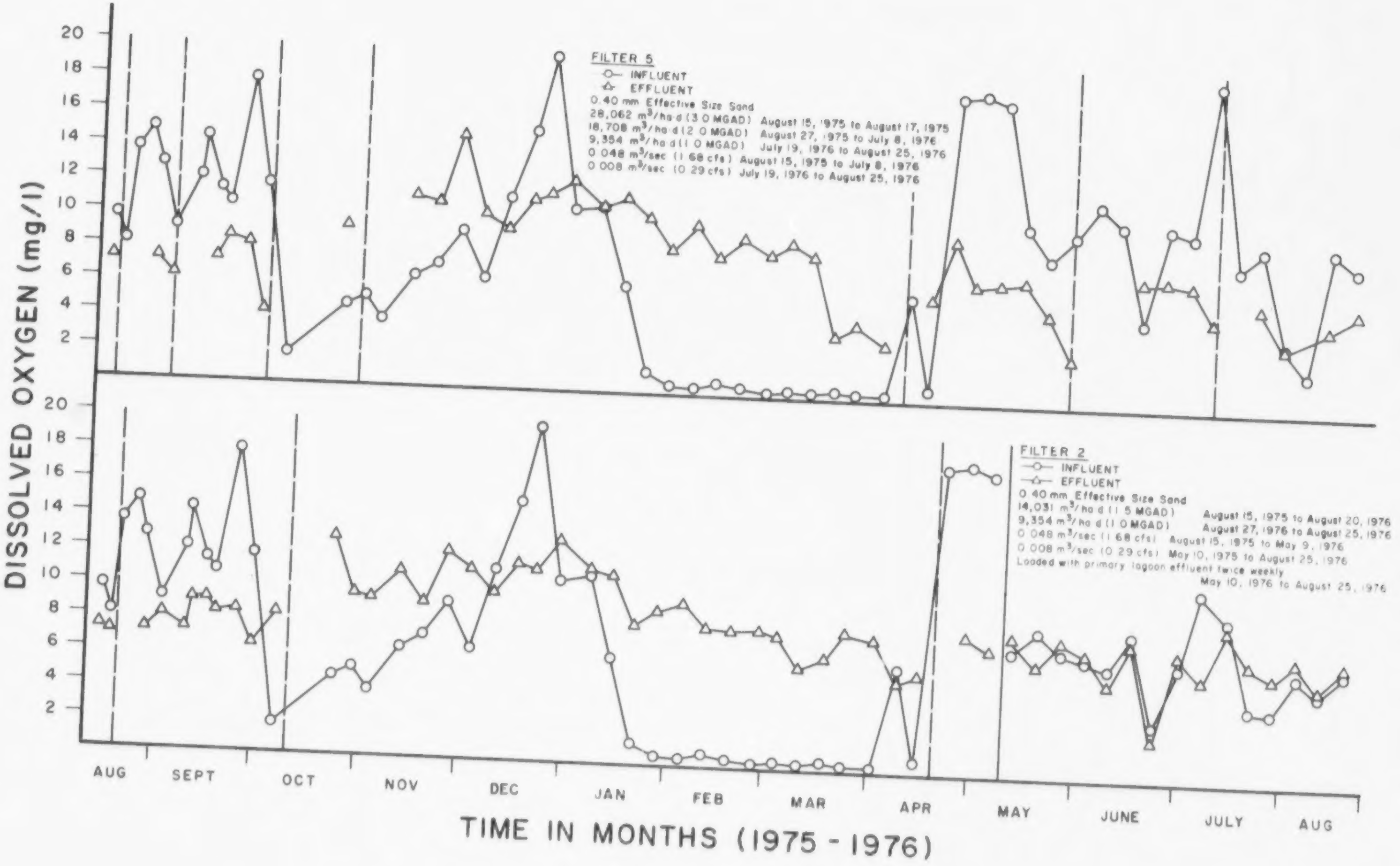

Figure 20. Continued.

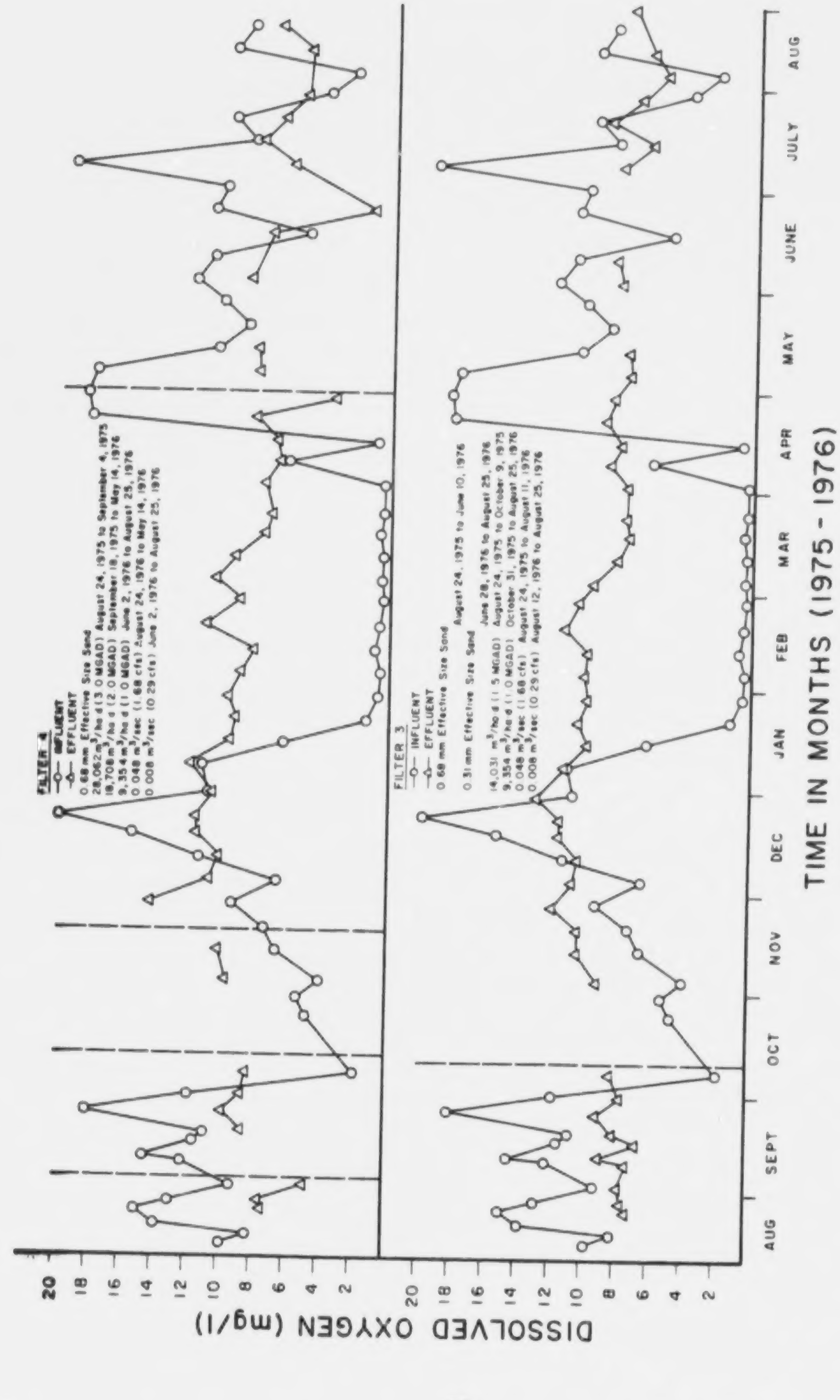

Figure 20. Continued.

Efficiency of 0.17 mm Effective Size Sand

The 0.17 mm effective size sands (Filters No. 1 and 6) with hydraulic loading rates of 3742 m^3/ha·d (0.4 MGAD) and 1871 m^3/ha·d (0.2 MGAD) produced an effluent with a DO concentration greater than 7 mg/l during 35 percent of the study. The mean yearly influent DO concentration was 8.5 mg/l and the mean yearly effluent DO concentration was 7.8 mg/l.

Summary

In general higher effluent dissolved oxygen (DO) concentrations were achieved with greater effective size sands. However, effluent DO concentrations were always greater than 4 mg/l for all effective size sands. Lower application rates appear to produce a lower effluent DO concentration; however, due to insufficient data a definite conclusion cannot be reached. Slightly lower effluent DO concentrations were observed during the summer months than during the winter months. In addition, a slight decrease in effluent DO concentration was observed just prior to the filters plugging.

CLIMATIC CONDITIONS

General

The intermittent sand filters performance was satisfactory under all climatic conditions. Ambient air temperatures varied from -21°C (-7°F) to 34°C (95°F). The influent temperature varied from 1.0°C (34°F) to 20°C (68°F). The effluent temperatures as shown in Figure 21 were similar to the influent temperature throughout the study.

Winter Operation

The six intermittent sand filters operated continuously during the winter months with little operational difficulties. The 0.17 mm effective size sand filters (Filters No. 1 and 6) with hydraulic loading rates of 3742 m^3/ha·d (0.4 MGAD) and 1871 m^3/ha·d (0.2 MGAD), respectively, experienced surface ice formations of 7.6 cm (3 inches) and 3.8 cm (1.5 inches) in thickness, respectively, caused by the slow filtration rate resulting from the 0.17 mm effective size sands and freezing temperatures. However, the ice layer caused no difficulty in filter operation. The 0.40 mm effective size sand (Filters No. 2 and 5) with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD), respectively, did not experience ice formation on the bed of the sand filter even during freezing temperatures because the wastewater remained on the filter less than 45 minutes (due to the higher infiltration rate of the 0.40 mm sand). The 0.68 mm effective size sand (Filters No. 3 and 4) with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD), respectively, performed in much the same manner as the 0.40 mm effective size sands (Filters No. 2 and 5). No ice cover formed on Filters No. 3 and 4 during freezing conditions due to the rapid infiltration of the water.

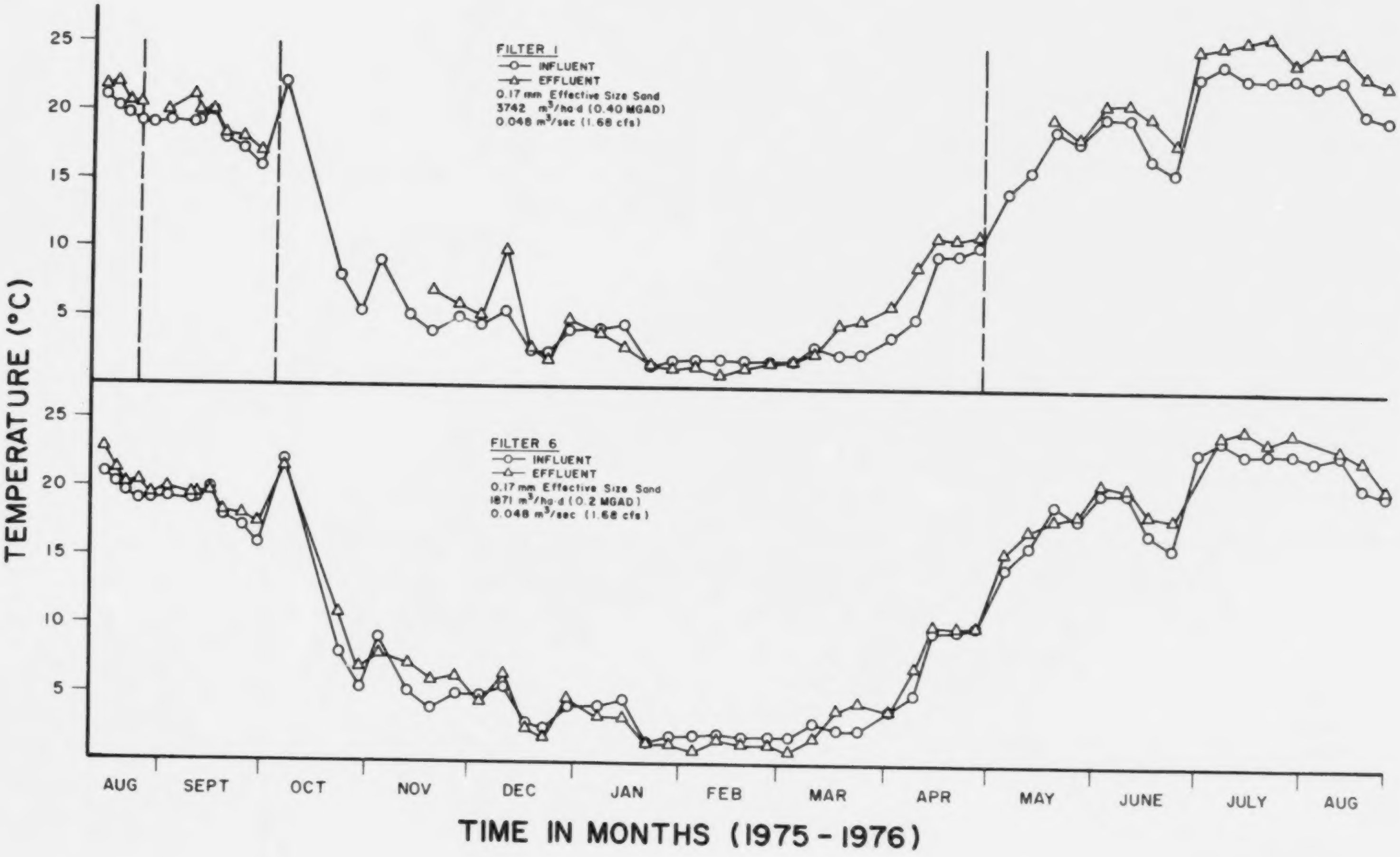

Figure 21. Weekly water temperature recordings.

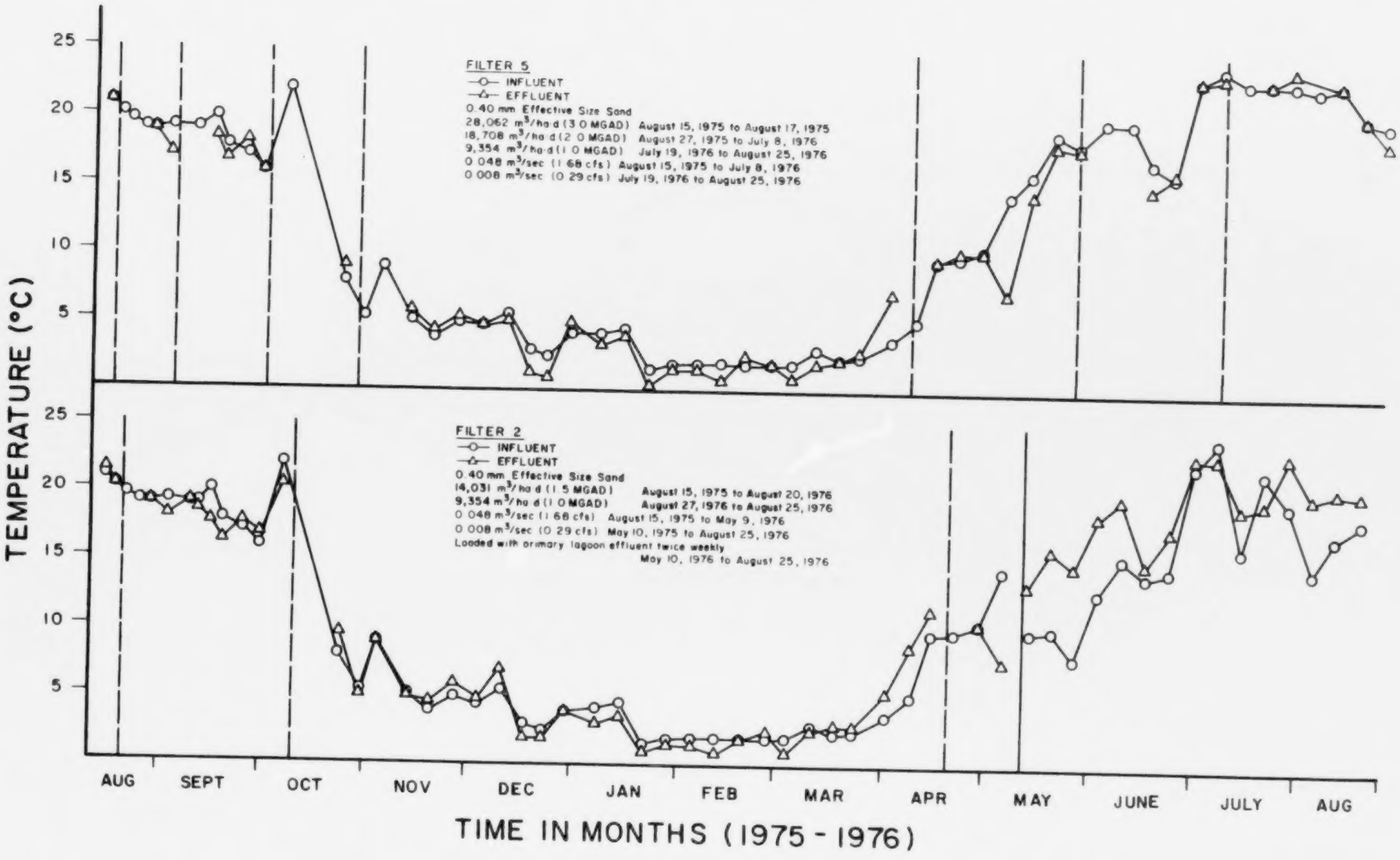

Figure 21. Continued.

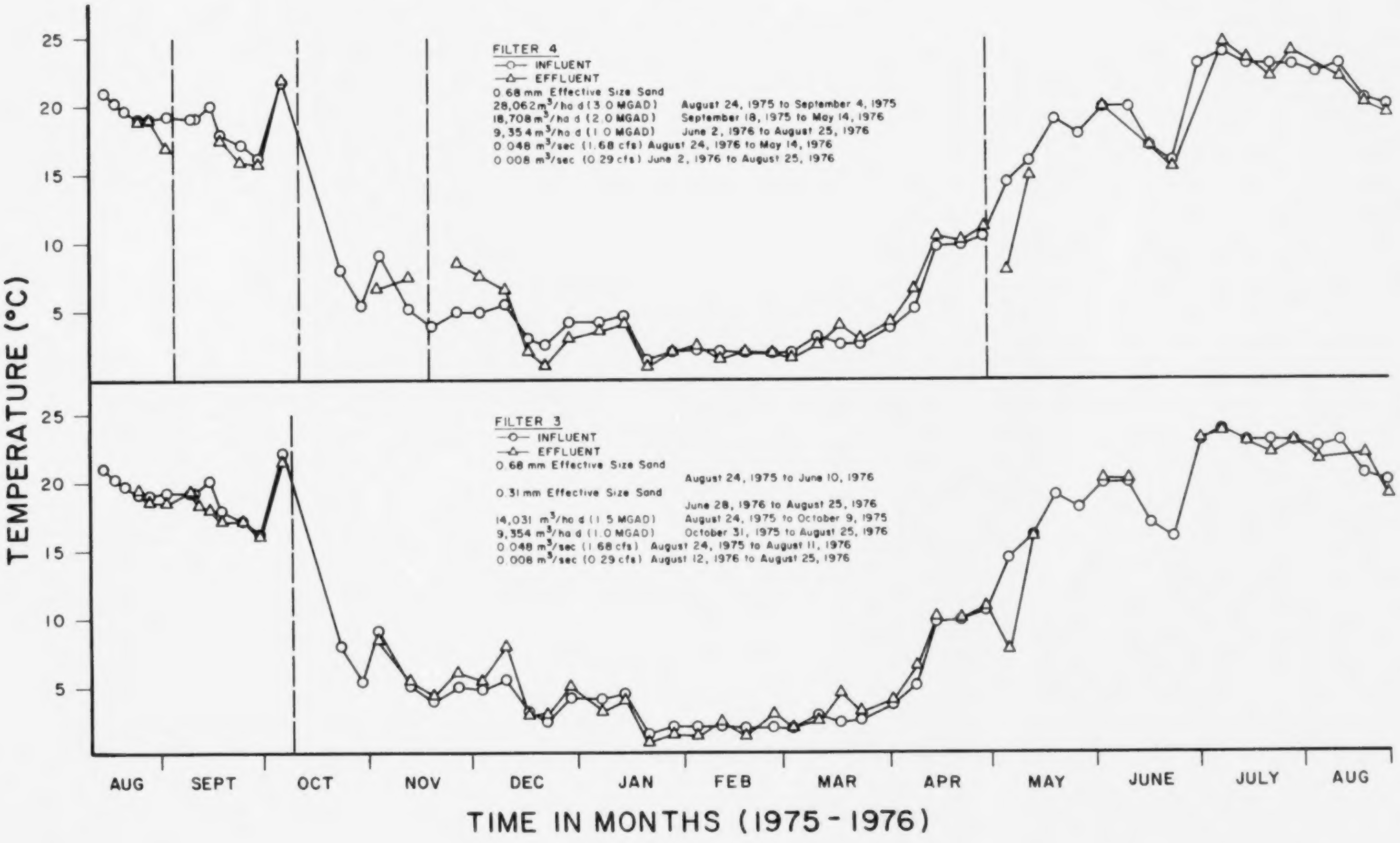

Figure 21. Continued.

Biological activity in the filters appeared to decrease during the colder weather as indicated by the BOD_5 performance shown in Figure 6. The average influent BOD_5 concentrations during December and January were 9 mg/l and during July and August were 13 mg/l. The 0.17 mm effective size sand with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) produced an average effluent BOD_5 concentration of 3 mg/l during December and January and 1 mg/l during July and August. The 0.17 mm effective size sand with a hydraulic loading rate of 1876 m^3/ha·d (0.2 MGAD) produced an average effluent BOD_5 concentration of 1 mg/l during December and January and less than 1 mg/l during July and August.

Warm Weather Operation

Warm weather increased the filter biological activity as illustrated by an increase in BOD_5 removal during the summer months (Figure 6).

During the warm months, high influent algae concentrations necessitated more frequent cleaning of the 0.40 mm effective size sands (Filters No. 2 and 5) with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and 18,708 m^3/ha·d (2.0 MGAD). Loading the filters during the hours of darkness may help to increase the filter run lengths (Reynolds et al., 1974) and reduce the frequency of cleaning.

The 0.17 mm effective size sand (Filter No. 6) with a hydraulic loading rate of 1871 m^3/ha·d (0.2 MGAD) experienced a heavy growth of weeds on the filter during May 1976 and August 1976. The plants were removed in May 1976, but the August 1976 plants were not removed because the study ended before September 1976.

Obnoxious odors occurred during the months of July and August 1976 on the 0.31 mm, 0.40 mm, and 0.68 mm effective size sands (Filters No. 2, 3, 4, and 5) receiving 9354 m^3/ha·d (1.0 MGAD) at an application rate of 0.008 m^3/sec (0.29 cfs). However, the odors did not persist beyond approximately 10 m (30 ft) of the filters. This unpleasant odor was probably caused by decaying organic matter on the filter surface.

Summary

Northern Utah's climate presented few problems to year-round operation of intermittent sand filters. Warm temperatures (summer operation) increased biological activity, increasing BOD_5 and COD removal and oxidation of nitrogen. Potential problems that may occur during the summer months include odor production and weed growth on the filter bed.

BACTERIAL REMOVAL PERFORMANCE

Total and fecal coliform removal efficiency was determined for the 0.17 mm, 0.31 mm, 0.40 mm, and 0.68 mm effective size sands. The results are tabulated in Appendix A, Tables A-8 to A-11.

Influent geometric mean total coliform concentrations ranged from 198 organisms/100 ml to 6.6 x 10^4 organisms/100 ml. The effluent geometric mean total coliform concentrations ranged from 81 organisms/100 ml with the 0.17 mm effective size sand to 2.6 x 10^4 organisms/100 ml with the 0.31 mm effective size sand. In general, total coliforms were not significantly reduced by filtration through any of the various effective size sands. Also, removal percentage appeared to be independent of the effective size of the sand. Several samples indicated an increase in total coliform as the lagoon effluent passed through the filter sand. However, such increases were slight and were not observed consistently. This is probably due to the growth of microorganisms within the filter bed.

Influent geometric mean fecal coliform concentrations ranged from 30 organisms/100 ml to 2.6 x 10^4 organisms/100 ml. Effluent geometric mean fecal coliform concentrations ranged from <1 organism/100 ml with the 0.68 mm effective size sand to 1.8 x 10^3 organisms/100 ml with the 0.40 mm effective size sand. Fecal coliform removal appeared to be independent of sand size. In addition to the overall removal of fecal coliforms by all sand sizes was not substantial.

It appears that both total and fecal coliform bacteria are not substantially removed by any of the various effective size sands studied and that disinfection of the filtered effluent will be required to satisfy State of Utah and Federal discharge requirements.

ALGAE AND ZOOPLANKTON REMOVAL

Influent Algae Genera

Individual alga genera counts are reported in Table A-9 of Appendix A. Palmella sp. was the predominant influent alga during the initial months of study. However during October 1975 the Palmella sp. disappeared and the Microcystis sp. became the predominant influent alga. Cryptomonas sp. and Chlamydomonas sp. were frequently observed from August 1975 to April 1976. During the summer months of the study Microcystis sp. and other blue green algae were predominant in the influent. In addition high concentrations of Euglenoids sp. were observed during the summer months. Microcystis sp. was observed throughout the study.

Influent Zooplankton Count

Influent zooplankton were counted during December and the latter months of study. Zooplankton counts were low in December and high near the conclusion of the study. Influent zooplankton counts as high as 420 per liter were observed during July.

Filter Performance

High rates of algae removal were observed for the lower effective size sands. However, the algal removal performance of the 0.31 mm effective size sand (Filter No. 3) did not exceed the 0.68 mm and 0.40 mm effective size sand algal performance. The 0.17 mm effective size sands (Filters No. 1 and 6) consistently removed 70 percent or more of the influent algae concentration. The 0.40 mm effective size sands (Filters No. 2 and 5) showed a slightly higher algal removal performance than the 0.68 mm effective size sands (Filters No. 3 and 4). Both effective size sands produced erratic influent algal removals, ranging from 0 percent to 95 percent, but the wide variation in percent removal may be due to the low influent algae concentrations. Poor algae removal was observed by the 0.17 mm, 0.40 mm, and the 0.68 mm effective size sands (Filters No. 1, 2, 3, 4, 5, and 6) when influent algae concentrations were 100/ml or less.

Complete influent zooplankton removal was observed by all intermittent sand filters during the entire experiment.

LENGTH OF FILTER OPERATION

General

The finer effective size sands produced a superior effluent in all categories measured. However, this higher efficiency was attained at the expense of a filter run length. Table 23 and Figure 22 show the effect of effective size sand, hydraulic loading rate, and application rate on filter run length before plugging.

Filter Rejuvenation

Three methods of rejuvenating a plugged filter were attempted. These methods included (i) complete removal of the top layer of sand (scraping), (ii) resting the filter after initial plugging for several days before attempting to reapply wastewater, and (iii) burning off the solids collected on the filter surface. Complete removal of five to ten centimeters of plugged filter sand proved most successful.

Resting the sand bed involved less maintenance, but short filter run lengths were obtained. The 0.40 mm effective size sand (Filter No. 5) with a hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD) was rested 22 days after initial plugging and then wastewater was again applied at the respective loading rate. It operated only 6 days before plugging occurred. The 0.68 mm effective size sand (Filter No. 4) with a hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD) operated 19 days before plugging again after being allowed to rest for 19 days following the initial plugging.

Rejuvenation of the plugged filters, which had earlier been allowed to rest (i.e., Filter No. 4 and 5) required scraping 15 centimeters (6 inches) off the filter surface. The clogging penetration of the filters, which had earlier been allowed to rest, was the deepest observed during the entire study.

Burning the plugged filter surface was not successful. A propane weed burner, used as the source of heat, merely darkened the filter surface and did not penetrate into the clogged sand layer to combusted the material clogging the pores.

TABLE 23. FILTER RUN LENGTHS ACHIEVED BY THE VARIOUS EFFECTIVE SIZE SANDS DURING THE STUDY

Effective Size Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Suspended Solids Removal (kg)	Volatile Suspended Solids Removal (kg)	Method of Rejuvenation	Consecutive Days of Operation
0.17	1,871	0.048	121.03	100.17	N.A.	374[+]
0.17	3,742	0.048	14.19	10.26	Scraped	11
0.17	3,742	0.048	29.69	22.65	Scraped	36
0.17	3,742	0.048	55.95	53.47	Scraped and Rested 14 Days	166
0.17	3,742	0.048	75.56	68.68	N.A.	103
0.31	9,354	0.048	44.43	48.29	N.A.	45
0.31	9,354	0.008	5.45	15.02	N.A.	14
0.40	9,354	0.048	40.92	63.31	Scraped	44
0.40	9,354	0.048	59.10	60.08	Scraped	177
0.40	9,354	0.048	20.47	19.73	N.A.	17
0.40	9,354	0.008	42.06	39.41	N.A.	37
0.40	14,031	0.048	20.03	17.31	Scraped	6
0.40	18,708	0.048	15.25	20.26	Scraped	7
0.40	18,708	0.048	28.33	37.35	Rested 22 Days	18
0.40	18,708	0.048	0.00	2.86	Scraped	6
0.40	18,708	0.048	68.00	67.77	Scraped	148
0.40	18,708	0.048	87.01	65.71	Scraped	42
0.40	18,708	0.048	61.98	57.34	Scraped	23
0.40	28,062	0.048	0.00	17.89	Scraped	3
0.68	9,354	0.048	71.67	79.46	N.A.	196
0.68	9,354	0.008	124.20	98.16	N.A.	84
0.68	14,031	0.048	102.03	102.57	Scraped	46
0.68	18,708	0.048	51.31	42.43	Rested 19 Days	23
0.68	18,708	0.048	0.00	11.93	Scraped	19
0.68	18,708	0.048	101.26	106.82	Scraped	152
0.68	18,708	0.048	14.95	12.85	N.A.	11
0.68	28,062	0.048	46.36	47.22	Scraped	11
	Loaded With Primary Lagoon Effluent Twice Weekly					
0.40	9,354	0.008	62.25	72.74	N.A.	30

[+] Filter operated 280 days, weeds removed, operation continued another 94 days until the study terminated.

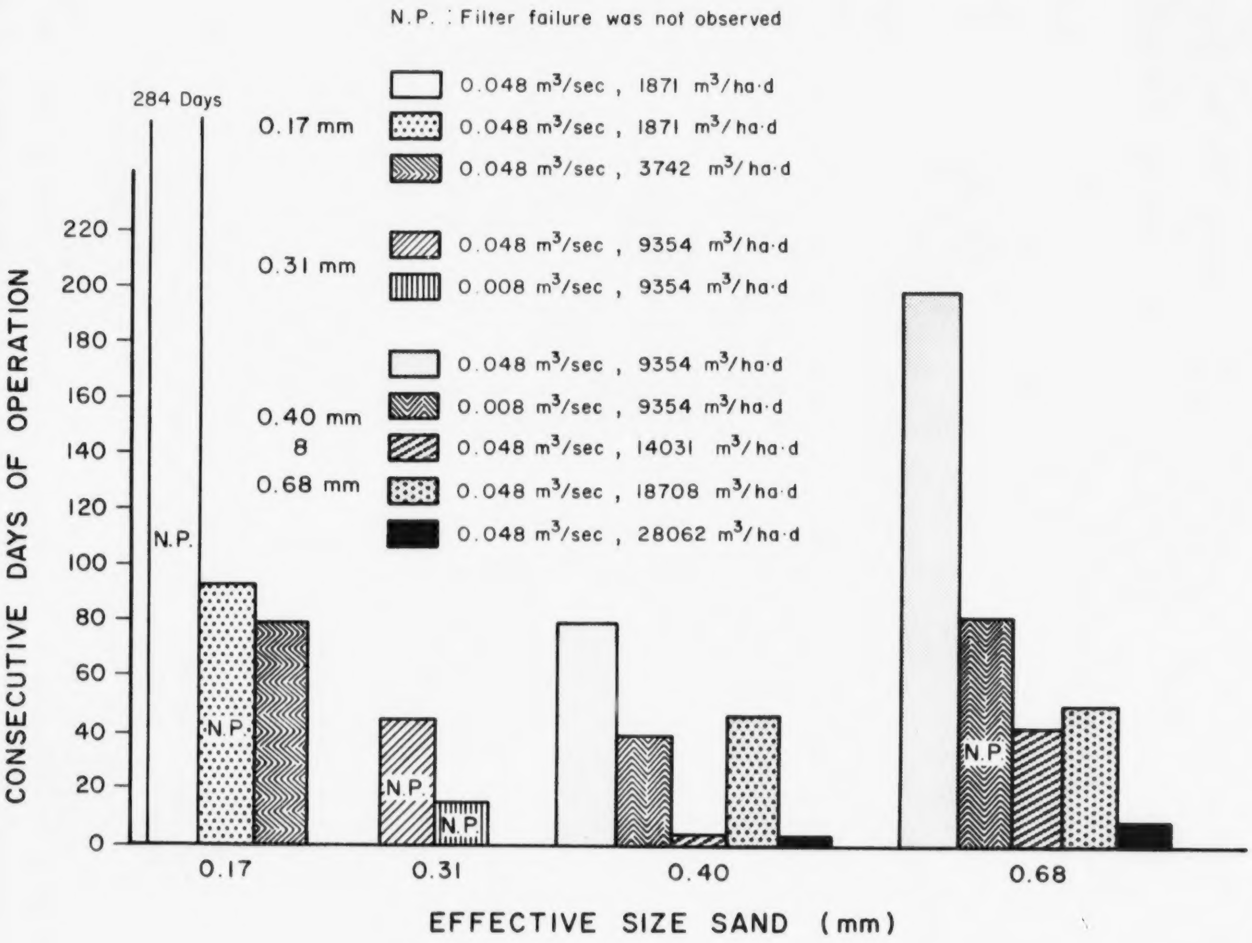

Figure 22. Bar graph illustrating the average length of filter operations with various effective size sands, hydraulic loading rates, and application rates.

Efficiency of 0.68 mm Effective Size Sand

The 0.68 mm effective size sand (Filter No. 4) with a hydraulic loading rate of 28,062 m^3/ha·d (3.0 MGAD) produced a low filter run length of 11 days, but removed nearly 47 kg (103 lbs) of influent suspended solids. A filter run length of 196 consecutive days without plugging was achieved with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD), removing 72 kg (158 lbs) of influent suspended solids. A hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD) produced a very satisfactory filter run length of 152 days removing more than 100 kg (220 lbs) of influent suspended solids. The 0.68 mm effective size sand (Filter No. 4) with a hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD) following a resting period of 19 days operated for only 23 days when wastewater was reapplied.

Efficiency of 0.40 mm Effective Size Sand

The 0.40 mm effective size sand (Filter No. 5) with a hydraulic loading rate of 28,062 m^3/ha·d (3.0 MGAD) operated 3 days before plugging occurred, removing 18 kg (39 lbs) influent volatile suspended solids. The 0.40 mm effective size sand (Filter No. 2) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) operated 177 consecutive days and removed 60 kg (132 lbs) influent SS prior to plugging. Performance of the 0.40 mm effective size sand filter (Filter No. 5) with a hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD) was similar to the 0.40 mm effective size sand (Filter No. 2) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) and removed 68 kg (150 lbs) of influent suspended solids during 148 consecutive days of operation.

Harris et al. (1975) studying the 0.17 mm effective size sand with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) reported a filter run length of less than 60 days with removals of 166 kg (364 lbs) of suspended solids. More influent suspended solids were removed during the Harris et al. (1975) study, but shorter filter run lengths were reported.

The 0.40 mm effective size sand (Filter No. 5) with a hydraulic loading rate of 18,708 m^3/ha·d (2.0 MGAD) operated six consecutive days before plugging. During this run no influent suspended solids removal was reported (due to experimental error); however, 3 kg (6 lbs) of influent volatile suspended solids were removed.

Suspended solids and volatile suspended solids removed by the 0.40 mm effective size sand (Filter No. 2) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) and an application rate of 0.008 m^3/sec (0.29 cfs) of primary lagoon effluent loaded twice weekly exceeded the suspended solids and volatile suspended solids removal by the other 0.40 mm effective size sands receiving secondary lagoon effluent by a factor of four. The 0.40 mm effective size sand (Filter No. 2) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) of primary lagoon effluent loaded twice weekly, and an application rate of 0.008 m^3/sec (0.29 cfs) removed 62 kg (136 lbs) of influent suspended solids and 72 kg (158 lbs) of influent volatile suspended solids during 30 nonconsecutive days of operation.

Efficiency of 0.31 mm Effective Size Sand

The 0.31 mm effective size sand (Filter No. 3) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) did not plug during the short study period. The 0.31 mm effective size sand filter (Filter No. 3) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) showed poor influent suspended solids and volatile suspended solids removal, removing 44 kg (96.8 lbs) of influent suspended solids and 48 kg (106 lbs) of influent volatile suspended solids during 45 consecutive days of operation without plugging.

Efficiency of 0.17 mm Effective Size Sand

The 0.17 mm effective size sand (Filter No. 1) with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) produced very satisfactory filter run lengths of 166 and 103 consecutive days and removed 56 kg (123 lbs) of influent volatile suspended solids and 76 kg (167 lbs) of influent suspended solids, respectively. Harris et al. (1975) reported average filter run lengths for the 0.17 mm effective size sand with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) of 33 days. The average filter run length reported by this study for the 0.17 mm effective size sand filter with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) is 79 days, which exceeds that reported by Harris et al. (1975) by a factor of two. However, Harris et al. (1975) reported a substantially higher total influent suspended solids removal of 234 kg (514 lbs) compared to 76 kg (167 lbs) influent suspended solids for this study.

To remove the anaerobic condition that was present in the sand filter bed, the 0.17 mm effective size sand filter (Filter No. 1) with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) was allowed to rest 14 days following plugging on April 29, 1976. The anaerobic condition was created by the continued hydraulic loading of the intermittent sand after plugging occurred (operational error). Influent seepage through the embankment prevented the detection of the plugged condition at an earlier date. The 0.17 mm effective size sand filter (Filter No. 1) with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) resumed operation on May 14, 1976.

Superior filter run length performance was observed for the 0.17 mm effective size sand (Filter No. 6) with a hydraulic loading rate of 1871 m^3/ha·d (0.2 MGAD). The 0.17 mm filter operated throughout the entire study without plugging. Vascular weed growth on the filter surface was removed in May to maintain equal filtration over the surface area; yet at the time of weed removal the filter showed no signs of plugging. The 0.17 mm filter (Filter No. 6) operated 280 consecutive days prior to the weed removal. After weed removal, this same filter operated another 94 consecutive days with no visible signs of plugging. The 0.17 mm filter (Filter No. 6) removed 121 kg (266 lbs) of influent suspended solids.

Harris et al. (1975) studying the 0.17 mm effective size sand with a hydraulic loading rate of 1871 m^3/ha·d (0.2 MGAD) reported similar total influent suspended solids and volatile suspended solids removals of 118 kg (260 lbs) and 91 kg (200 lbs), respectively.

Summary

High hydraulic loading rates of 28,062 m^3/ha·d (3.0 MGAD) resulted in short filter run lengths for the 0.40 mm and 0.68 mm effective size sands (Filters No. 2, 3, 4, and 5). Hydraulic loading rates of 18,708 m^3/ha·d (2.0 MGAD) and less, resulted in satisfactory filter run lengths for the 0.40 mm and 0.68 mm effective size sands (Filters No. 2, 3, 4, and 5). The 0.17 mm effective size sand (Filter No. 6) with a hydraulic loading rate of 1871 m^3/ha·d (0.2 MGAD) did not plug during the one year study. The 0.17 mm effective size sand (Filter No. 1) with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) produced satisfactory filter run lengths. Due to insufficient data from the 0.31 mm effective size sand filter (Filter No. 3) and the 0.68 mm and 0.40 mm effective size sand filters (Filters No. 4 and 5) with hydraulic loading rates of 9354 m^3/ha·d (1.0 MGAD) and a low application rate of 0.008 m^3/sec (0.29 cfs), no conclusion can be reached. However, data collected thus far, suggest that filter run length may be increased by lowering the application rate.

SAMPLING OF SUSPENDED SOLIDS WITH TIME

General

During the first month of operation of the 0.31 mm, 0.40 mm, and 0.68 mm effective size sand filters (Filters No. 2, 3, 4, and 5), high effluent suspended solids (SS) concentrations were observed. The high effluent suspended solids concentration was due to the removal of fine sands and dirt from the filter bed. However, after the initial month of operation, effluent SS concentrations no longer exceeded influent SS concentration. This suggests that an intermittent sand filter requires an initial washing cycle to remove the fine sands and grit.

In addition, high effluent suspended solids concentrations were observed at the beginning of each daily effluent run. This phenomenon is referred to as "wash out." Tests were performed on all effective size sands, 0.17 mm, 0.31 mm, 0.40 mm, and 0.68 mm effective size sands with various application rates to determine the extent of the "wash-out" and whether the sampling performed by this study was representative of intermittent sand filter performance. Figures 23, 24, 25, 26, 27, 28, 29, and 30 show the effluent suspended solids concentrations with time. A slight increase in effluent SS concentration was generally observed during the latter stages of daily operation. This suggests that algal growth may be occurring in the ponded wastewater above the filter surface (Reynolds et al., 1974).

Variations in influent SS and volatile suspended solids (VSS) concentrations with time were studied to determine the extent of influent SS and VSS fluctuation and to determine if one sample is representative of the influent SS and VSS concentration during a four hour period. Figure 23 illustrates the influent SS and VSS concentrations with time. During a four hour period, the mean influent SS concentration was 46 mg/l with a standard deviation of 2.1 mg/l. The mean influent VSS concentration during the same four hour period was 23 mg/l with a standard deviation of 1.6 mg/l. Influent

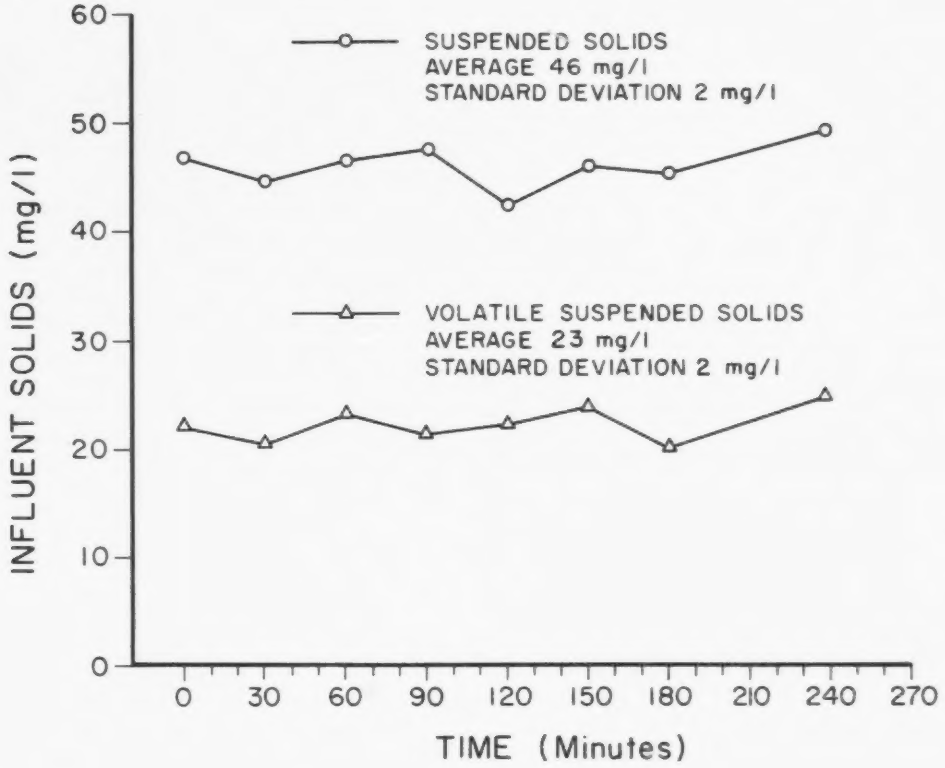

Figure 23. Influent suspended solids and volatile suspended solids concentrations with time.

SS and VSS concentrations were relatively constant and the variation between samples is probably due to the analytical technique employed (APHA, AWWA, WPCF, 1971). The low standard deviations indicate that one influent SS and VSS sample is sufficient during the four hour period employed.

0.68 mm Effective Size Sand

The 0.68 mm effective size sand (Filter No. 5) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) required 10 minutes (Figure 24) to remove the fine sands and grit accumulated from the previous day's operation. Lowering the application rate to 0.008 m^3/sec (0.29 cfs) resulted in no change in time (Figure 25) necessary to stabilize daily filter operation. However, change in application rates from 0.48 m^3/sec (1.68 cfs) to 0.008 m^3/sec (0.29 cfs) produced a change in length of daily filter operation from 30 minutes to 155 minutes.

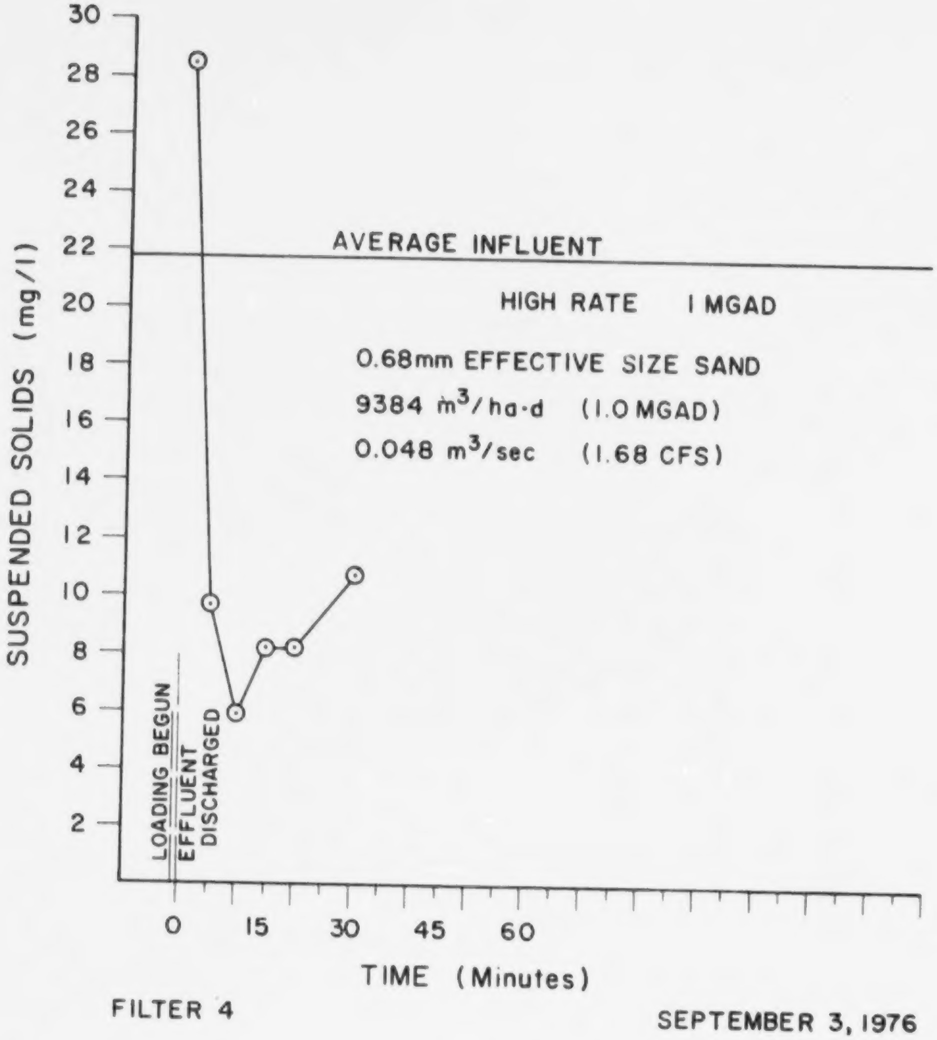

Figure 24. Suspended solids with time of the 0.68 mm effective size sand filter with an application rate of 0.048 m^3/sec (1.68 cfs).

0.40 mm Effective Size Sand

The effluent suspended solids concentration compared with time for the 0.40 mm effective size sand (Filter No. 5) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) is similar (Figure 26) to the 0.68 mm effective size sand (Filter No. 4) performance (Figure 24). The length of the "wash-out" period was 5 minutes (Figures 26 and 27) for application rates of 0.048 m^3/sec (1.68 cfs) and 0.008 m^3/sec (0.29 cfs). Decreasing the application rate from

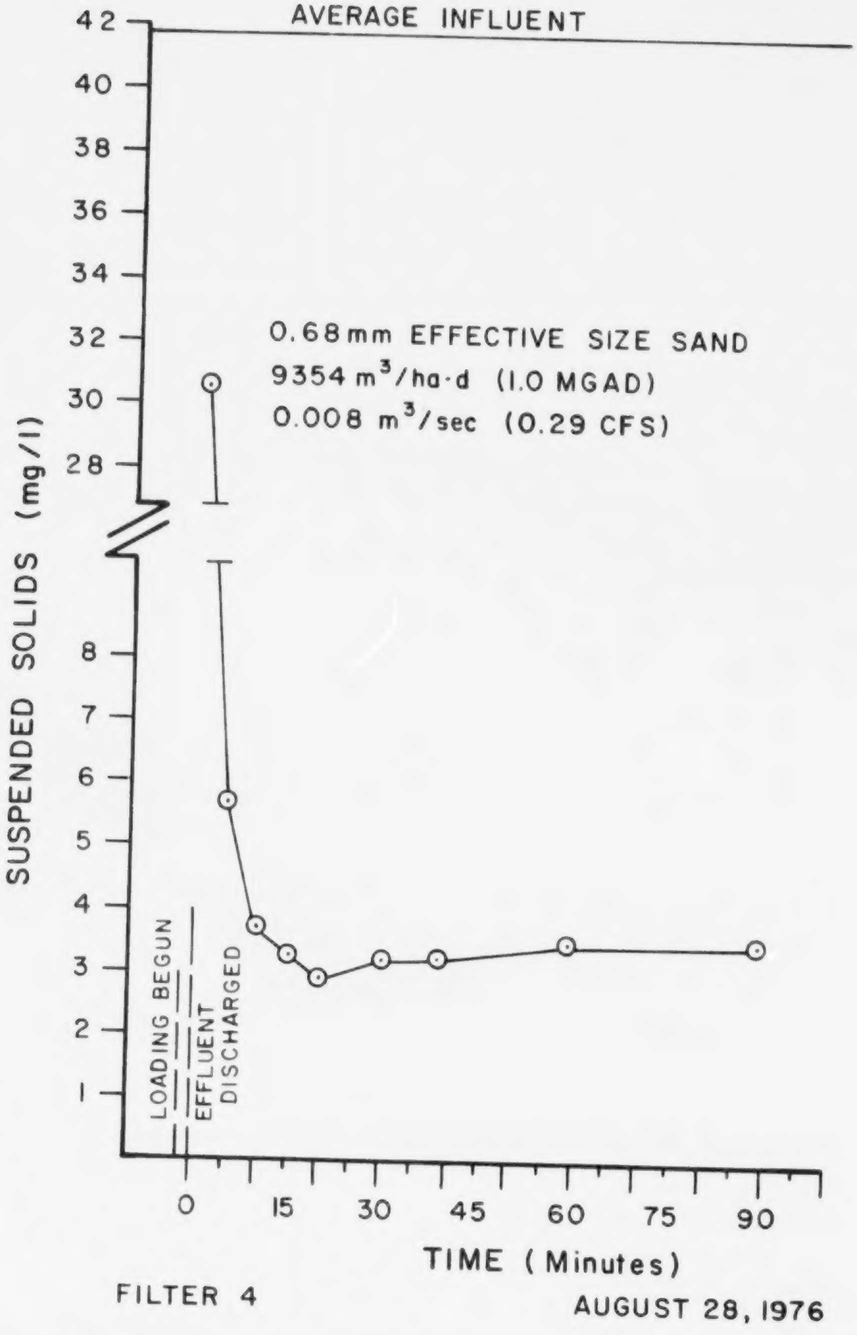

Figure 25. Suspended solids with time of the 0.68 mm effective size sand filter with an application rate of 0.008 m^3/sec (0.29 cfs).

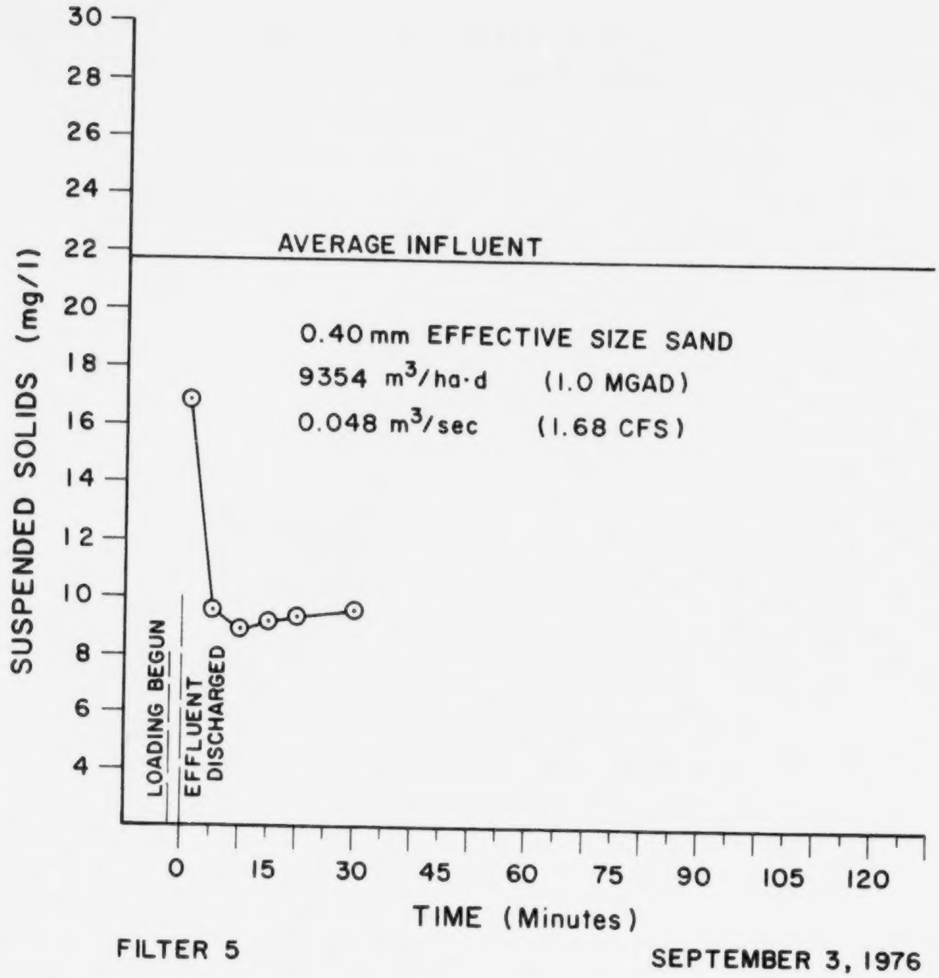

Figure 26. Suspended solids with time of the 0.40 mm effective size sand filter with an application rate of 0.048 m^3/sec (1.68 cfs).

0.048 m^3/sec (1.68 cfs) to 0.008 m^3/sec (0.29 cfs) increased the length of filter operation from 35 minutes to 160 minutes.

0.31 mm Effective Size Sand

A time lapse of 15 minutes (Figure 28) was necessary for the 0.31 mm effective size sand (Filter No. 3) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) and application rates of 0.048 m^3/sec (1.68 cfs) 0.008 m^3/sec (0.29 cfs) to remove the fine sands and grit accumulated from the previous day's operation. The length of daily operation of the 0.31 mm effective size sand (Filter No. 3) nearly doubled (Figure 29) when the

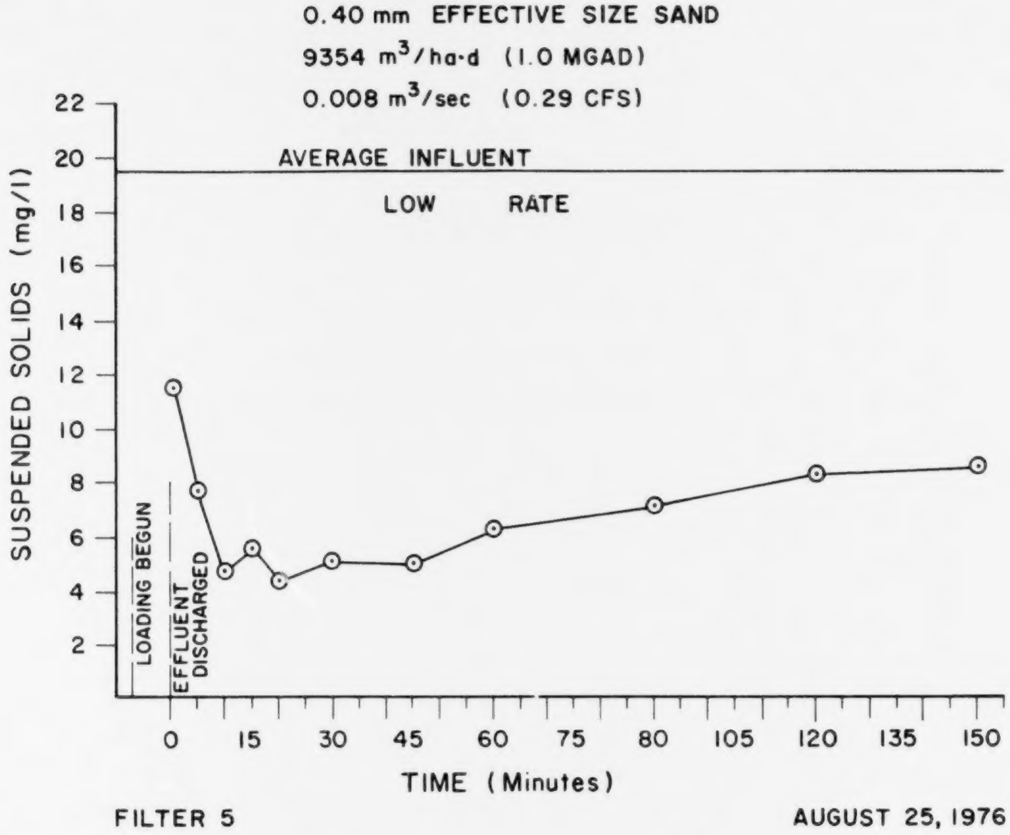

Figure 27. Suspended solids with time of the 0.40 mm effective size sand filter with an application rate of 0.008 m^3/sec (0.29 cfs).

application rate was decreased to 0.008 m^3/sec (0.29 cfs) from 0.048 m^3/sec (1.68 cfs).

0.17 mm Effective Size Sand

The 0.17 mm effective size sand (Filter No. 1) with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) required a "wash-out" period of 45 minutes (Figure 30). The length of daily filter operation exceeded 3.5 hours, though a consistent trickle of effluent was observed from the discharge pipe between loadings.

Summary

Application rate did not produce a change in the length of time required for daily filter "wash-out." The 0.31 mm, 0.68 mm, and 0.40 mm effective size

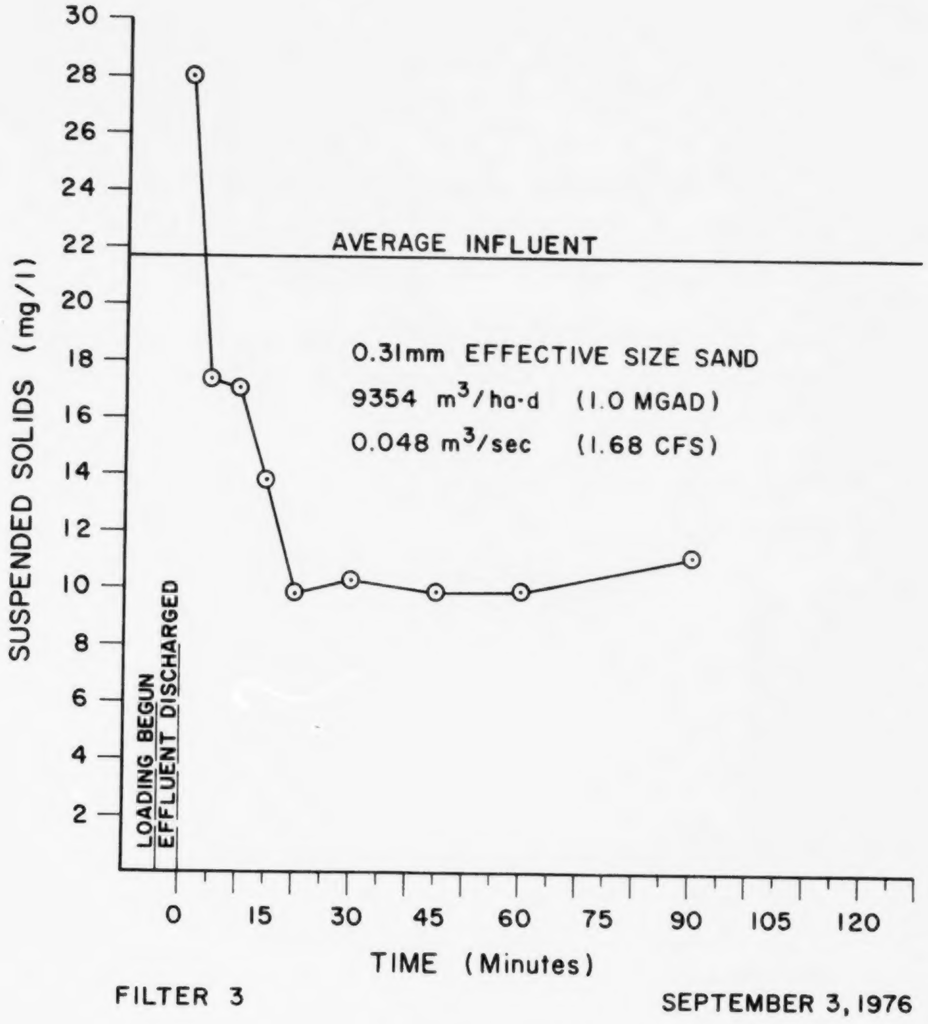

Figure 28. Suspended solids with time of the 0.31 mm effective size sand filter with an application rate of 0.048 m^3/sec (1.68 cfs).

sands (Filters No. 3, 4, and 5, respectively) produced similar "wash-out" effects (requiring 15, 10, and 5 minutes respectively to remove the fine sands and grit accumulated from the previous days loading). A 45 minute "wash-out" period was required for the 0.17 mm effective size sand filter (Filter No. 1); however, very little effluent was observed to leave the filter during the initial 20 minutes of operation.

Influent suspended solids and volatile suspended solids concentrations fluctuated very little during a four hour period; therefore, one sample

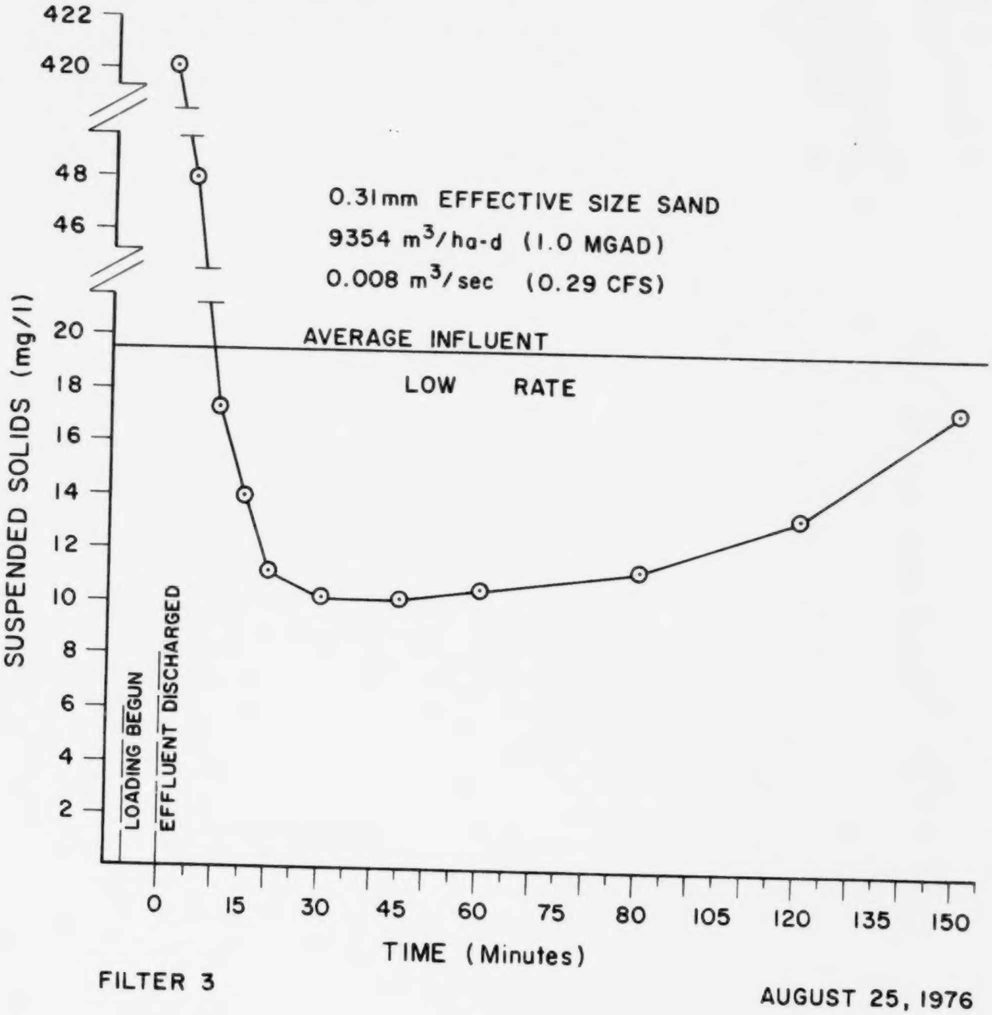

Figure 29. Suspended solids with time of the 0.31 mm effective size sand filter with an application rate of 0.008 m^3/sec (0.29 cfs).

may be considered representative of the influent SS and VSS concentrations during a four hour period.

SAMPLING BIOCHEMICAL OXYGEN DEMAND WITH TIME

General

The effluent biochemical oxygen demand (BOD_5) concentrations with time for the various effective size sands (Filters No. 1, 3, 4, and 5) are shown

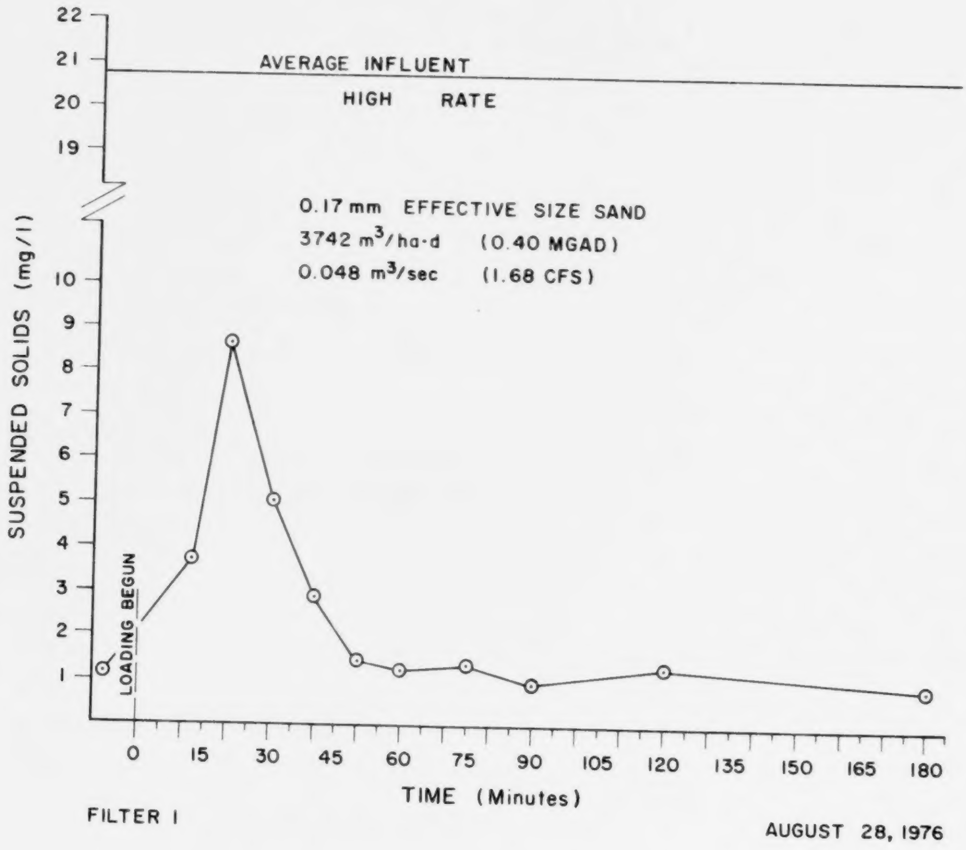

Figure 30. Suspended solids with time of the 0.17 mm effective size sand filter.

in Figures 31, 32, 33, 34, 35, 36, 37, and 38. The effluent BOD_5 performance with time is similar to the effluent suspended solids performance with time. During the initial minutes of daily filter operation, high effluent BOD_5 concentrations were observed. Thus, indicating removal of organic matter that may have accumulated from the previous day's hydraulic loading or may have grown in the filter bed since the previous day's hydraulic loading. The effluent BOD_5 performance with time was erratic after the initial discharge. Several factors which may have influenced this phenomena are: (i) error in the BOD_5 test, (ii) erratic influent BOD_5 concentration, or (iii) the bacterial activity (i.e., growth of organic matter) in the sand filter bed is not constant.

Variations in influent BOD_5 concentration with time were studied, and, Figure 31 illustrates the results. During a three hour study, the average influent BOD_5 concentration was 7 mg/l with a standard deviation of 1.0 mg/l.

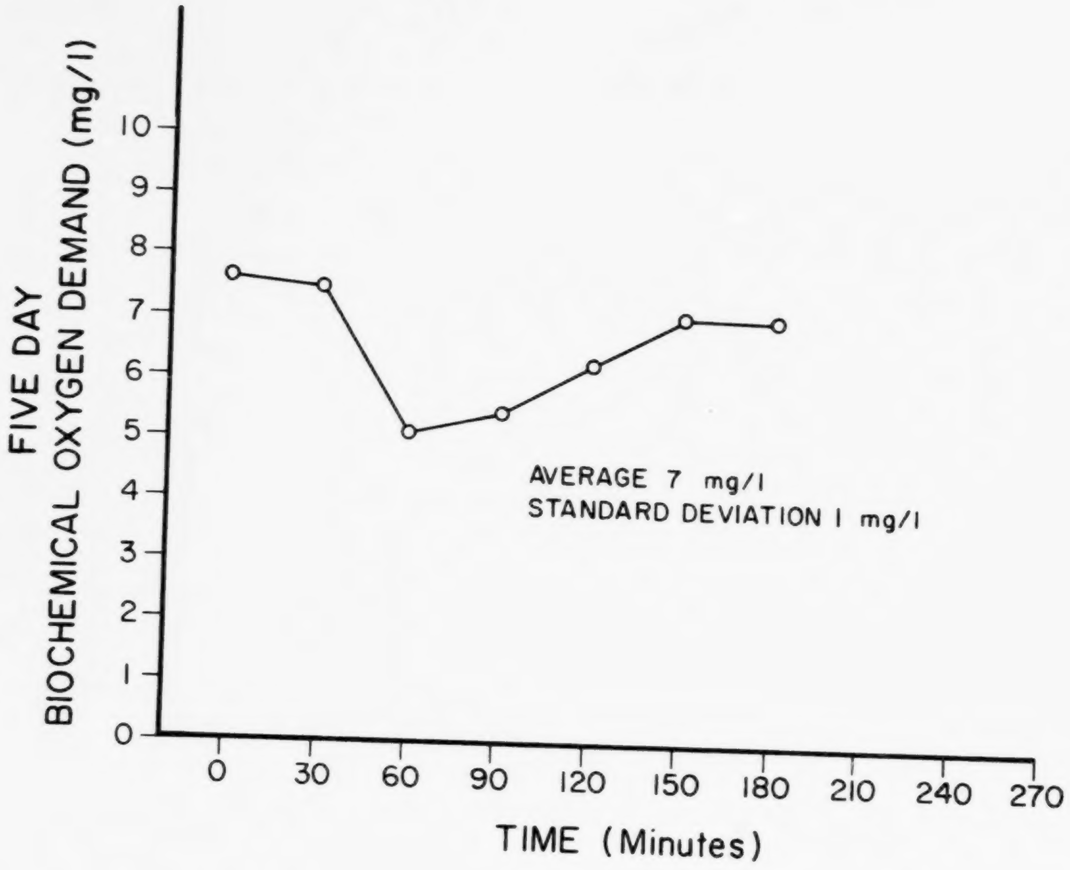

Figure 31. Influent biochemical oxygen demand (BOD_5) with time.

The standard deviation is representative of the accuracy attainable by the 5-day biochemical oxygen demand test (APHA, AWWA, WPCF, 1971), suggesting that one influent BOD_5 sample is sufficient during a three hour period of sampling.

0.68 mm Effective Size Sand

Application rates of 0.008 m^3/sec (0.29 cfs) and 0.048 m^3/sec (1.68 cfs) required 15 (Figure 32) and 5 (Figure 33) minutes, respectively, before a uniform effluent BOD_5 concentration was observed for the 0.68 mm effective size sand (Filter No. 4) with a hydraulic loading rate 9354 m^3/ha·d (1.0 MGAD).

0.40 mm Effective Size Sand

The 0.40 mm effective size sand (Filter No. 5) with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) and a low application rate of 0.008 m^3/sec

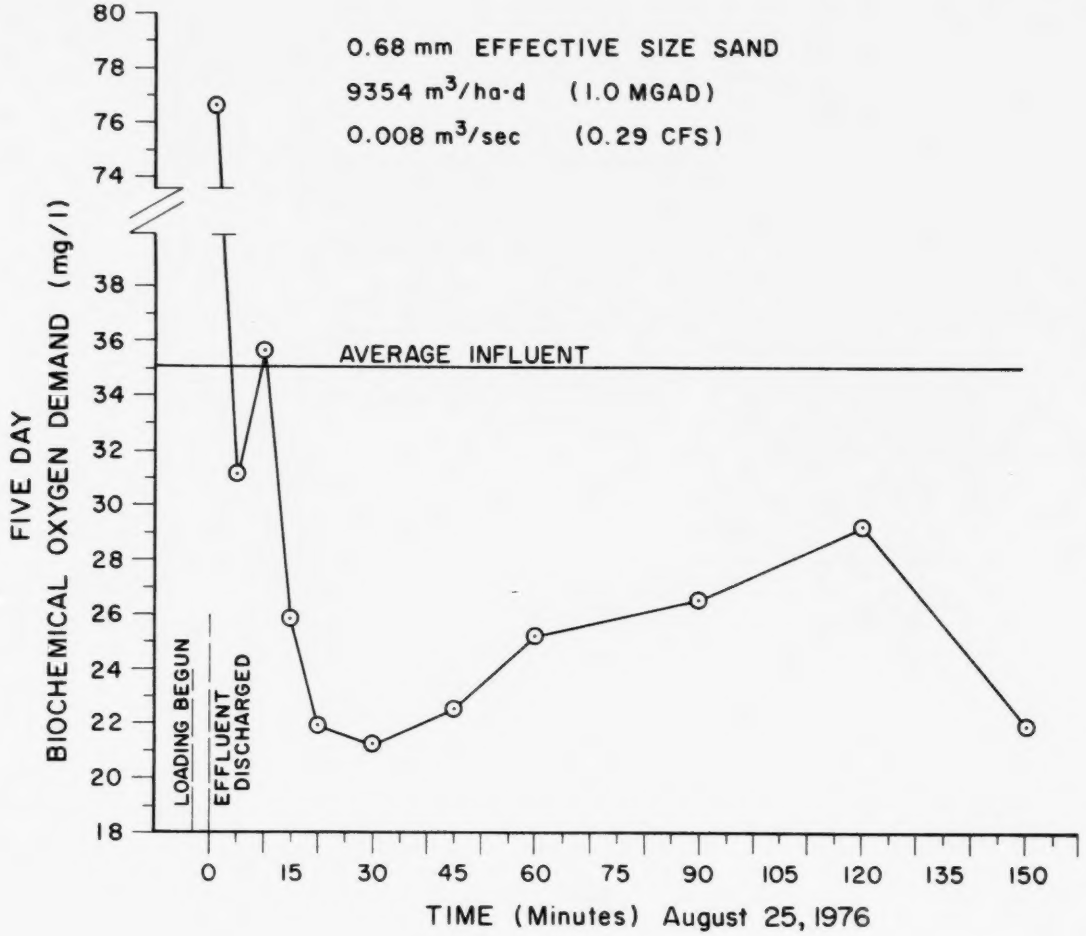

Figure 32. Biochemical oxygen demand (BOD_5) with time of the 0.68 mm effective size sand filter with an application rate of 0.008 m^3/sec (0.29 cfs).

(0.29 cfs) produced very erratic effluent BOD_5 concentrations with time during the 2.5 hours of operation (Figure 34). Increasing the application rate to 0.048 m^3/sec (1.68 cfs) for the 0.40 mm effective size sand filter (Filter No. 5) gave a consistent and stable effluent BOD_5 performance after 5 minutes of filter operation (Figure 35).

0.31 mm Effective Size Sand

The effluent BOD_5 performance with time for the 0.31 mm effective size sand (Filter No. 3) is very similar (Figure 36) to the effluent BOD_5

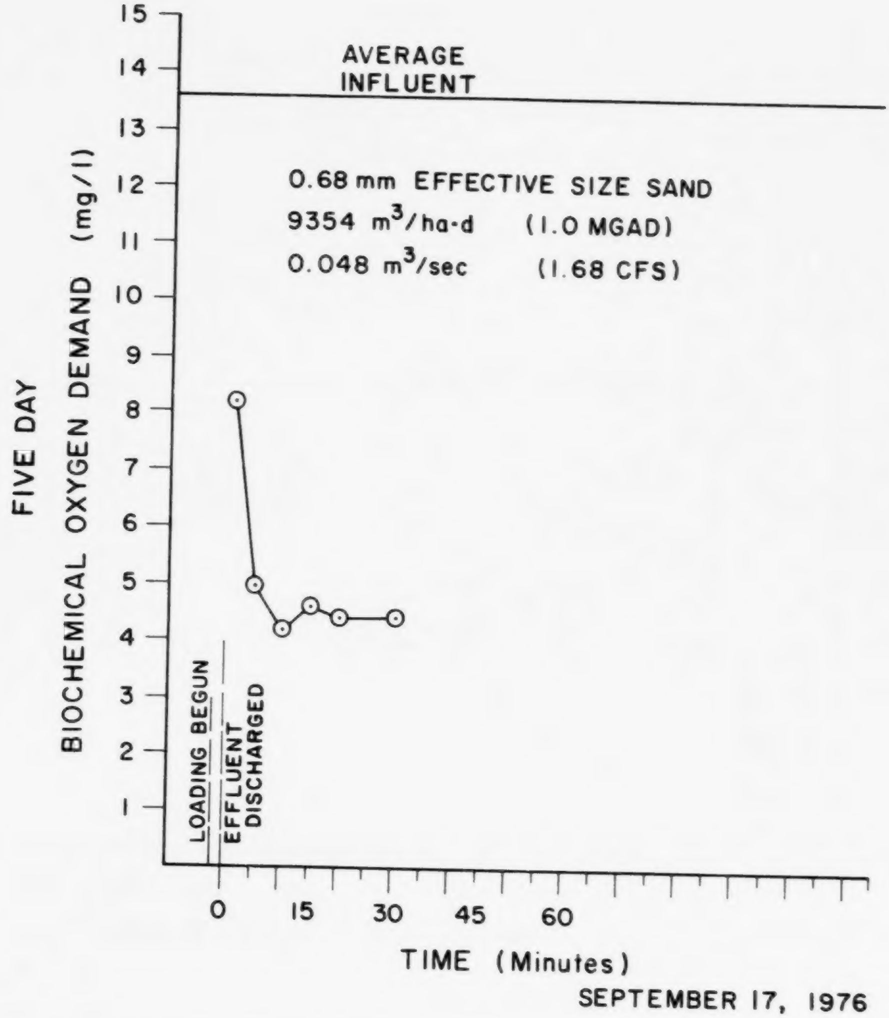

Figure 33. Biochemical oxygen demand (BOD_5) with time of the 0.68 mm effective size sand filter with an application rate of 0.048 m^3/sec (1.68 cfs).

performance of the 0.40 mm effective size sand (Filter No. 4) with similar operating conditions (Figure 35). The 0.31 mm effective size sand with a hydraulic loading rate of 9354 m^3/ha·d (1.0 MGAD) produced a uniform effluent BOD_5 concentration (Figure 36) with time operating with a high application rate of 0.048 m^3/sec (1.68 cfs). Lowering the application rate to 0.008 m^3/sec (0.29 cfs) gave very irregular effluent BOD_5 concentrations with time (Figure 37).

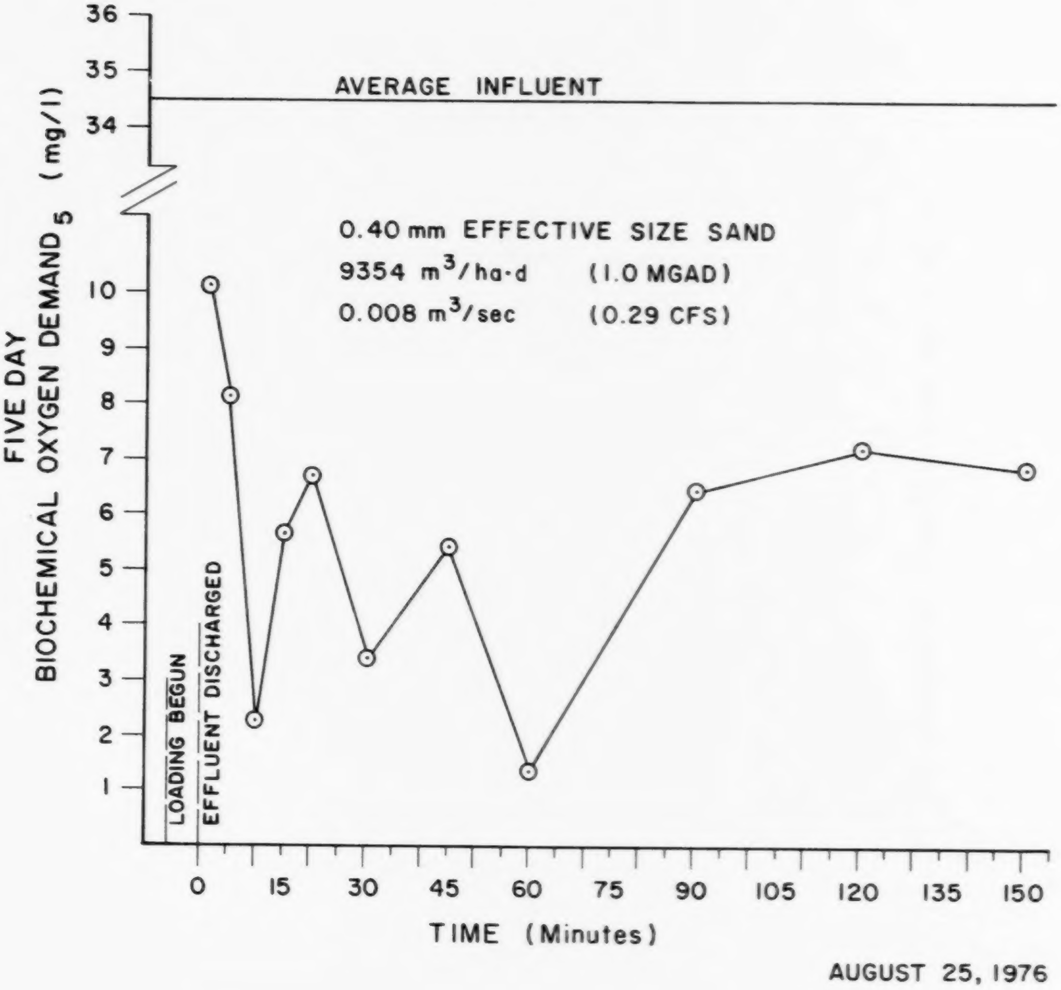

Figure 34. Biochemical oxygen demand (BOD$_5$) with time of the 0.40 mm effective size sand filter with an application rate of 0.008 m^3/sec (0.29 cfs).

0.17 mm Effective Size Sand

The 0.17 mm effective size sand (Filter No. 1) with a hydraulic loading rate of 3742 m^3/ha·d (0.4 MGAD) effluent BOD$_5$ revealed no significant change in effluent BOD$_5$ concentration with time (Figure 38). This may indicate that little organic matter is washed from the filter during the initial loading of daily operation.

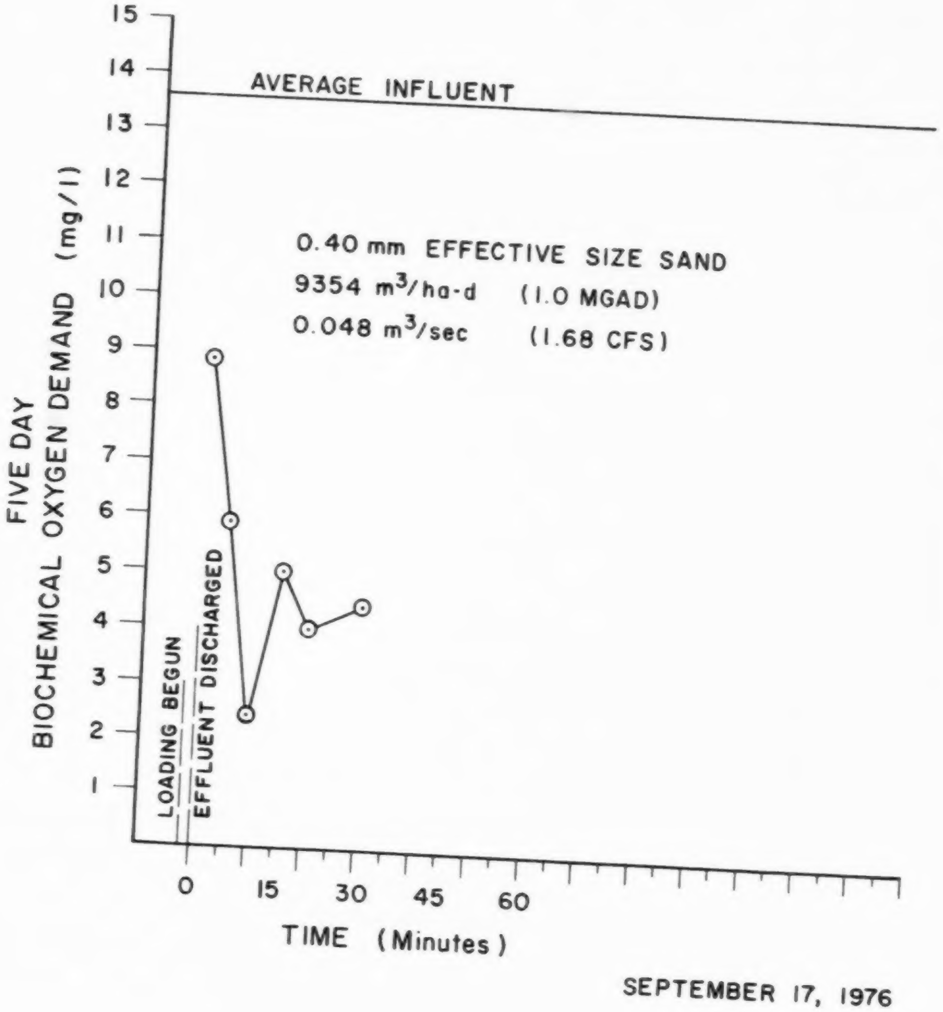

Figure 35. Biochemical oxygen demand (BOD_5) with time of the 0.40 mm effective size sand filter with an application rate of 0.048 m^3/sec (1.68 cfs).

Summary

A low application rate of 0.008 m^3/sec (0.29 cfs) produced a nonuniform effluent BOD_5 concentration with time for the 0.31 mm and 0.40 mm effective size sand filters (Filters No. 3 and 5).

High application rate of 0.048 m^3/sec (1.68 cfs) on the 0.31 mm, 0.68 mm, and 0.40 mm effective size sands (Filters No. 3, 4, and 5) indicated that the

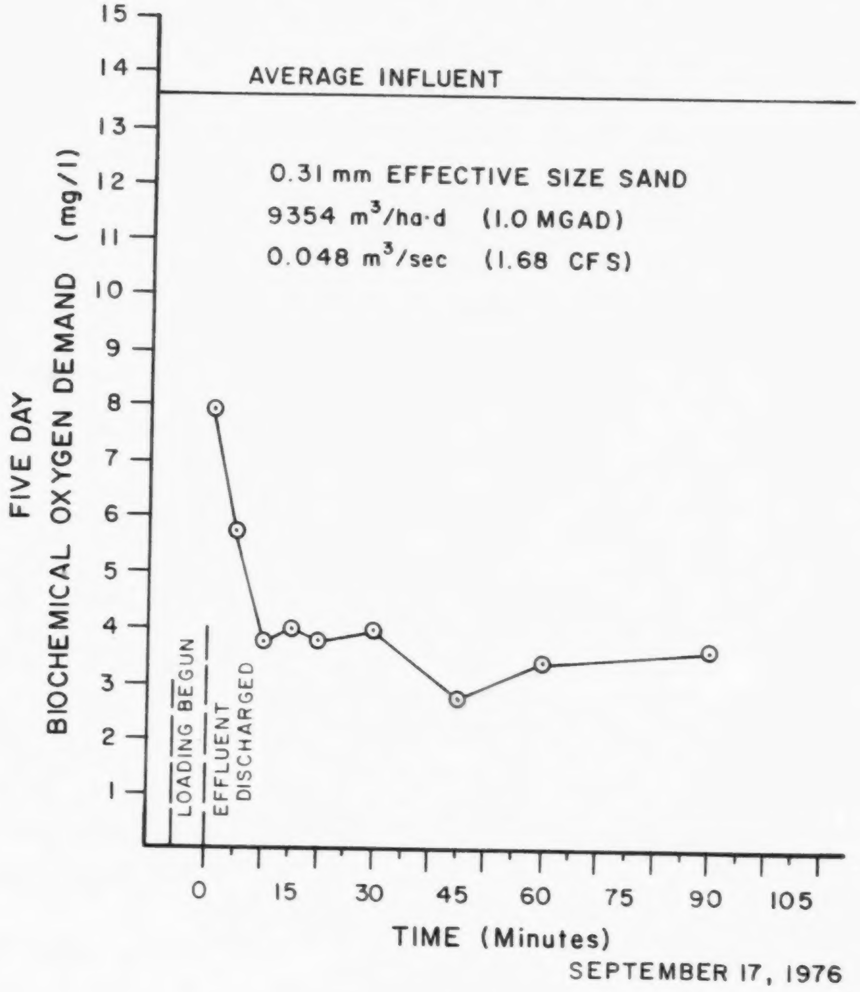

Figure 36. Biochemical oxygen demand (BOD_5) with time of the 0.31 mm effective size sand filter with an application rate of 0.048 m^3/sec (1.68 cfs).

variation of effluent BOD_5 concentration with time is similar to the variation in effluent SS concentration with time.

FINAL EFFECTIVE SIZE FILTER SAND ANALYSIS

At the conclusion of the study a final sieve analysis (Table 24) of the 0.17 mm and 0.68 mm effective size sands revealed a decrease to 0.12 mm and 0.64 mm effective size, respectively. The 0.40 mm effective size sand was

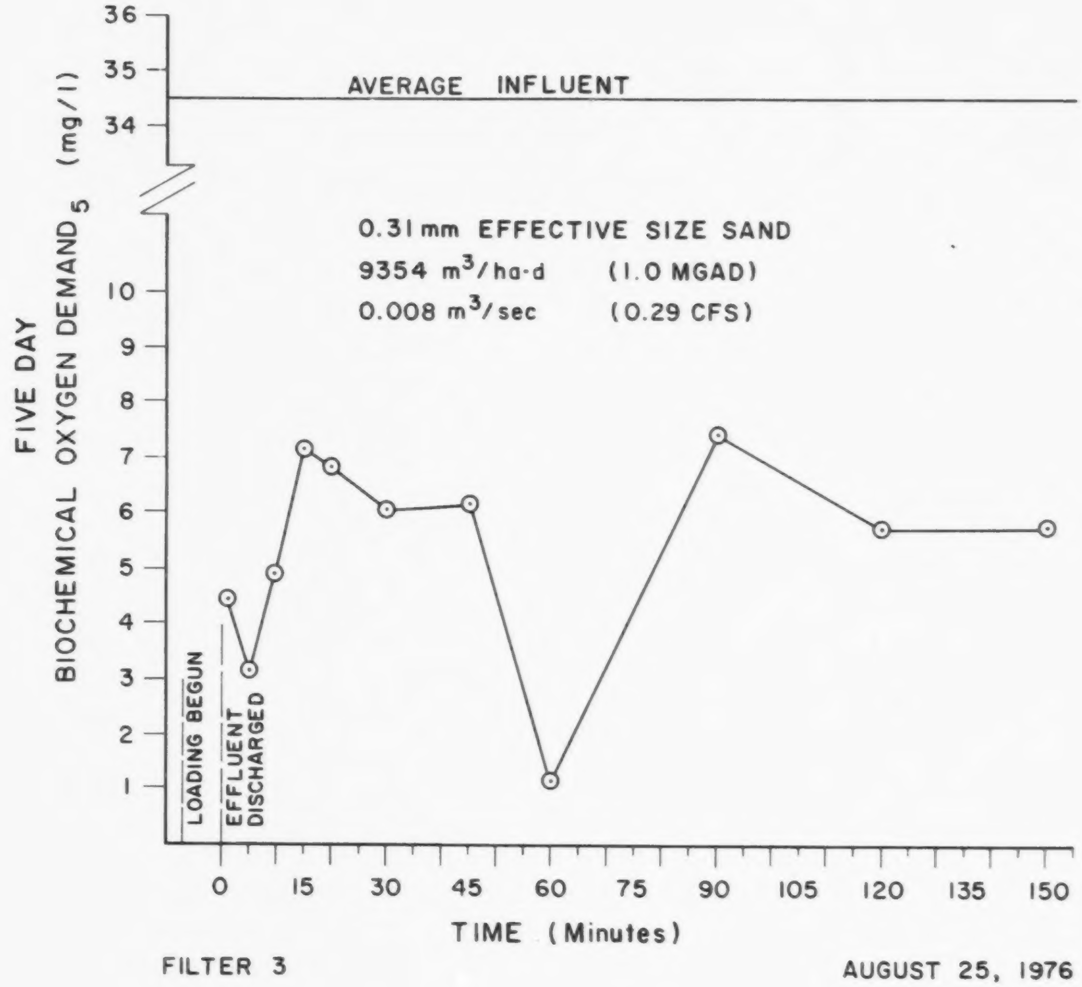

Figure 37. Biochemical oxygen demand (BOD_5) with time of the 0.31 mm effective size sand filter with an application rate of 0.008 m^3/sec (0.29 cfs).

determined to be 0.44 mm effective size. The discrepancies between initial and final effective size of the sands may be due to: (i) laboratory procedures, (ii) washing and removing of fine sands from the filter during operation, or (iii) the abrasive action on the sand, interface during operation of the filter. Hill (1976) reported a decrease in 0.40 mm effective size sand and little change in 0.17 mm and 0.72 mm effective size sands, after one year of operation.

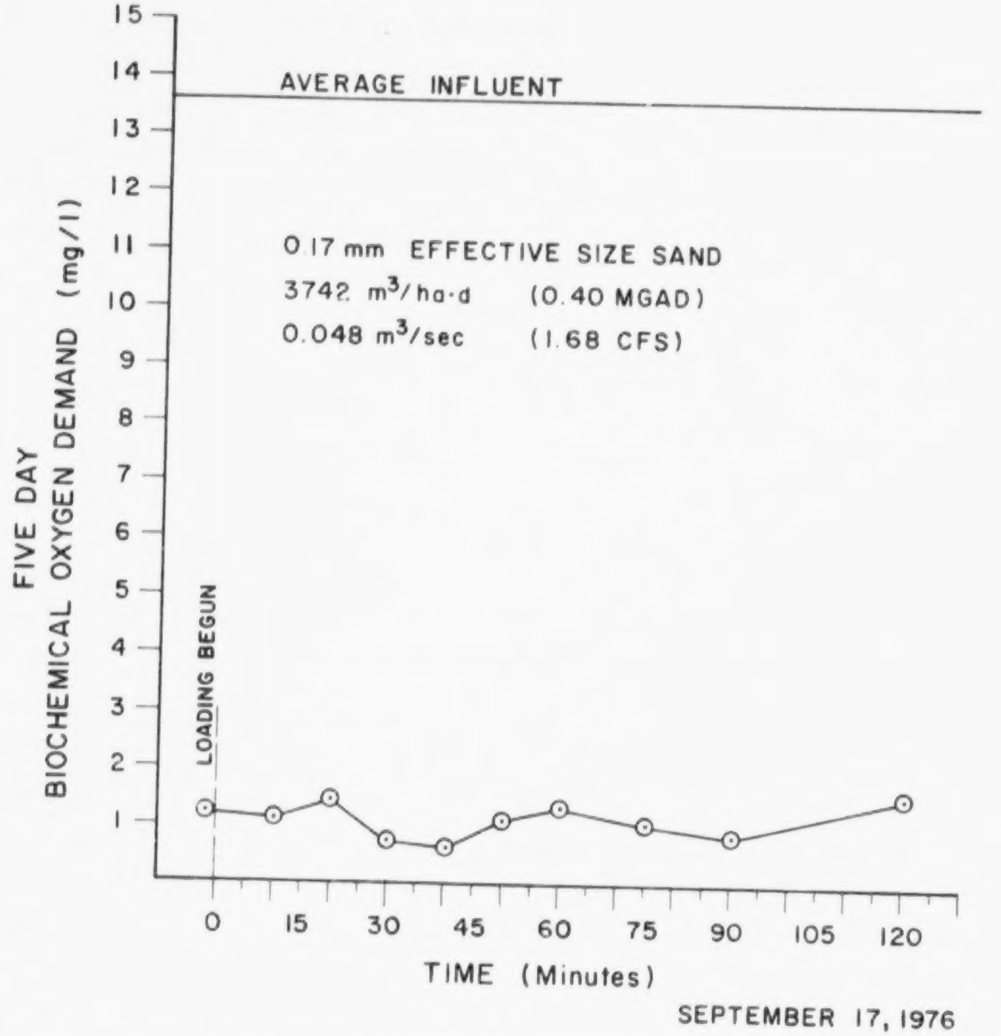

Figure 38. Biochemical oxygen demand (BOD_5) with time of the 0.17 mm effective size sand filters.

PERFORMANCE SUMMARY

A performance summary for each effective size sand compared to the State of Utah and Federal Secondary Treatment Standards is shown in Table 25. The biochemical oxygen demand (BOD_5) and suspended solids performance with respect to the Federal Secondary Treatment Standards are somewhat misleading. Table 25 indicates that all effective size sands complied with the Federal Secondary Treatment BOD_5 and suspended solids standard nearly all the time. However, the influent concentrations to the filter sands were generally less than the effluent quality required by the Federal Secondary Treatment

TABLE 24. FINAL SIEVE ANALYSIS OF FILTER SANDS

Sieve Size Number	Opening (mm)	Percent Passing Sample			
		A	B	C	D
4	4.760	95	95	89	84
8	2.380	--	67	--	--
10	2.000	71	61	47	49
16	1.190	61	45	31	--
30	0.590	47	25	14	7
40	0.420	--	--	--	--
50	0.297	28	9	5	3
100	0.149	13	5	1	--
Number of Samples		2	3	2	2
Final Effective Size, P_{10} (mm)		0.12	0.31	0.44	0.64
Initial Effective Size, P_{10} (mm)		0.17	0.31	0.40	0.68
Uniformity Coefficient, P_{10}/P_{60}		9.3	6.5	2.9	4.2

Standard. Thus, the various effective size sands were not stressed to satisfy the Federal standards.

Only the 0.17 mm effective size sand was capable of satisfying the State of Utah biochemical oxygen demand (BOD_5) and suspended solids standard consistently. No sand satisfied the State of Utah bacterial standards. In general, the finer sands meet the standards more often than the coarse sands.

TABLE 25. NUMBER OF MONTHS THE MONTHLY AVERAGE EFFLUENT CONCENTRATIONS OF VARIOUS EFFECTIVE SIZE SANDS SATISFIED THE STATE OF UTAH AND FEDERAL SECONDARY TREATMENT STANDARDS (INDEPENDENT OF INFLUENT CONCENTRATIONS)

Effective Size Filter Sand (mm)	Hydraulic Loading Rate (m^3/ha·d)	Application Rate (m^3/sec)	Federal Standard* (No./Total Possible)**				State of Utah+ (No./Total Possible)**				
			BOD_5	SS	pH (Median)	Fecal Coliform	BOD_5	SS	pH (Median)	Total Coliform	Fecal Coliform
0.17	1,871	0.048	13/13	13/13	13/13	N.A.	13/13	13/13	13/13	N.A.	N.A.
0.17	3,742	0.048	12/12	12/12	12/12	8/11	12/12	12/12	12/12	4/11	2/11
0.31	9,354	0.048	3/3	3/3	3/3	2/2	3/3	1/3	3/3	0/2	0/2
0.31	9,354	0.008	1/1	1/1	1/1	N.A.	1/1	0/1	1/1	N.A.	N.A.
0.40	9,354	0.048	10/10	9/10	9/10	2/9	6/10	6/10	9/10	0/9	0/9
0.40	9,354	0.008	2/2	2/2	2/2	N.A.	2/2	1/2	2/2	N.A.	N.A.
0.40	14,031	0.048	1/1	1/1	1/1	N.A.	1/1	0/1	1/1	N.A.	N.A.
0.40	18,708	0.048	12/12	10/12	10/12	N.A.	6/12	5/12	10/12	N.A.	N.A.
0.40	28,062	0.048	1/1	0/1	N.A.	N.A.	1/1	0/1	N.A.	N.A.	N.A.
0.68	9,354	0.048	8/8	8/8	6/8	N.A.	3/8	6/8	6/8	N.A.	N.A.
0.68	9,354	0.008	3/3	3/3	3/3	N.A.	3/3	0/3	3/3	N.A.	N.A.
0.68	14,031	0.048	3/3	3/3	3/3	N.A.	3/3	0/3	3/3	N.A.	N.A.
0.68	18,708	0.048	8/8	7/8	7/8	4/6	3/8	3/8	7/8	0/6	0/6
0.68	28,062	0.048	1/1	0/1	1/1	1/1	1/1	0/1	1/1	0/1	1/1
0.40^t	9,354	0.008	4/4	4/4	4/4		2/4	4/4	4/4		

N.A. = Not available.

**No. of months standard satisfied/total number of months in operation.

*$BOD_5 \leq 30$ mg/l; SS ≤ 30 mg/l; pH = 6.9; Fecal Coliform geometric mean $\leq 200/100$ ml.

+Based on June 30, 1980: $BOD_5 \leq 10$ mg/l; SS ≤ 10 mg/l; pH = 6.5-9.0; Tot. Col. geometric mean $\leq 200/100$ ml; Fecal Coli geometric mean $\leq 20/100$ ml.

^{t}Loaded with primary lagoon effluent twice weekly.

SECTION 7

INTERMITTENT SAND FILTER DESIGN

GENERAL

Based upon the data collected in this study, tentative design parameters have been formulated. Satisfying the Federal Secondary Treatment Standards and the State of Utah, discharge requirements were considered when establishing the design criteria. Construction, operation and economics costs of intermittent sand filters in this section reflect the conditions found in northern Utah and should not be directly applied to other areas without consideration of the variable construction and operating parameters.

A minimum of two intermittent sand filters per lagoon treatment facility is required to facilitate maintenance and adverse flow conditions. However, a flexible wastewater treatment facility should have four intermittent sand filters (ASCE-WPCF, 1959).

CONSTRUCTION

Embankments and Filter Bed

Shape and size of intermittent sand filters are dictated by the location, topography, length of outfall and pumping requirements. Intermittent sand filters should not exceed one acre (Metcalf and Eddy, 1935; Steel, 1960) and yet be of size to handle mechanical equipment for maintenance. Rectangular intermittent sand filters have been utilized most often but other shapes have been used effectively.

Embankments and filter beds should be constructed of relatively impervious materials compacted sufficiently (85 percent-95 percent) to form a stable structure, and help eliminate erosion, infiltration and exfiltration of neighboring bodies of water. Other methods of sealing the intermittent sand filter bed include vinyl liners, soil amendments, asphalt liners, and concrete.

Width of the embankment is dependent upon size of maintenance vehicles and size of the intermittent sand filters. To permit access of maintenance vehicles, a minimum embankment top width of 2.4 m (8 feet) is necessary. Many intermittent sand filters will not require a maintenance roadway on the embankment due to the small size of the intermittent sand filter. However all intermittent sand filters should contain a paved ramp leading onto the bed of the intermittent sand filter to allow easy access of maintenance equipment.

Interior slopes of the embankment should vary from 3:1 to 6:1, with rip rap or other protective material being placed on the slopes to prevent erosion and vegetation growth. Exterior slopes of the embankment, if needed, should not exceed 3:1 with perennial type, low growing and spreading grasses planted to prevent exterior erosion of the embankment.

Filter Drainage

Clay tile or perforated PVC piping may be used for collecting the effluent. The underdrains are usually placed in trenches below the bottom of the sand with 0.3 m (1 ft) of graded gravel, to make the entire depth of the sand effective for filtration. Lateral drains feeding into the main drain should be spaced approximately 4.6 m (15 feet) with all piping sloped to a slight grade (0.025) to provide a flow rate of 0.91 m/sec (3 fps) to 1.2 m/sec (4 fps) when flowing full to be self cleaning.

Filter Media

The bottom medium should be washed gravel, broken stone or blast furnace slag placed in three layers of varying sizes. About the underdrains a 3.3 cm (1.5 inch) maximum diameter rock may be placed that extends to 10.2 cm (4 inch) above the pipe. A 10.2 cm (4 inch) layer of 1.9 cm (0.75 inch) maximum diameter rock should proceed the 3.8 cm (1.5 inch) maximum diameter rock. A 0.6 cm (0.25 inch) maximum diameter rock layer of 10.2 cm (4 inch) concludes the support for the filter sand.

To satisfy the State of Utah, discharge requests the 0.17 mm effective size sand is recommended. The 0.17 mm effective size sand is available locally as pit run concrete sand. The higher effective size sands must either be transported from other areas or sieved at local gravel yards. The 0.31 mm, 0.40 mm and 0.68 mm effective size sands with a low application rate of 0.008 m^3/sec (0.29 cfs) appear to satisfy the State of Utah, discharge requirements; however, more study with low application rates should be performed before constructing with these layer sands.

Influent Distribution System

The method of influent distribution on the intermittent sand filters is dictated by the available head. A gravity fed system requires a total head of 10 feet for the intermittent sand filter system (ASCE and WPCF, 1959) to operate satisfactorily. Pumps may be utilized where insufficient head is available.

The means of distributing the influent over the intermittent sand filters need not be complex. Troughs with discharge ports may be used. The use of single corner or multiple corner side aprons of stone or concrete should be used on small intermittent sand filters [15 m by 15 m (50 feet by 50 feet) or smaller] as a means of flow distribution. An automated lagoon effluent discharge system with a manual override is recommended to allow the operation of intermittent sand filters at any desired time.

OPERATION

Hydraulic Loading Rates

Hydraulic loading rates of 1,871 m^3/ha·d (0.2 MGAD) and 3,742 m^3/ha·d (0.4 MGAD) on the 0.17 mm effective size filter sands produced an effluent that satisfied the State of Utah discharge requirements in all categories, except effluent total and fecal coliform concentrations. Multiple dosings per day should be considered as well as hydraulic loading during the evening to achieve the maximum efficiency possible.

Application Rate

The low infiltration rate coupled with low hydraulic loading rates utilized by the 0.17 mm effective size sand permit high application rates of 0.048 m^3/sec (1.68 cfs). Effluent quality from the 0.17 mm effective size sand filters does not change by varying the application rate.

Maintenance

Vegetation growth on the intermittent sand filters should be prevented by complete removal of the weeds or ranking the filter bed periodically. Any signs of erosion, filter seepage or pipe breakage should be repaired immediately to avoid further operational problems.

Plugged intermittent sand filters may be rejuvenated by several methods. Removal of the plugged filter surface was the most effective rejuvenation method experienced by this study. A 25 to 35 horsepower tractor with a rear 1.2 m (4 feet) to 1.8 m (6 feet) blade and a 0.9 m (3 feet) front end loader would eliminate much manual labor involved in scraping a plugged filter and minimize the down time of an intermittent sand filter.

The spent filter sand should be stockpiled to be washed and recycled to the intermittent sand filter (Elliott et al., 1976).

Construction and Operation Cost Estimate

A breakdown of the individual costs of construction of intermittent sand filters is presented in Appendix B. The unit prices quoted in Appendix B reflect general in-place estimates for northern Utah and costs will vary according to availability of materials, manpower, and pumping requirements.

Table 26 summarizes the cost of 3 different designs of single-stage intermittent sand filters. Total costs given in this paper include operating and maintenance costs.

A design flow of 3,785 m^3/d (1.0 MGD) and a hydraulic loading rate of 9,354 m^3/ha·d (1.0 MGAD) is estimated to cost $45 per million gallons of filtrate including operation and maintenance costs with 75 percent federal assistance. Utilizing the same design flow of 3,785 m^3/ha·d (1.0 MGAD), and decreasing the hydraulic loading rate to 3,742 m^3/ha·d (0.4 MGAD) increases the total estimated cost including operation and maintenance costs

TABLE 26. ESTIMATED COST PER MILLION GALLONS OF FILTRATE PRODUCED BY VARIOUS DESIGNS OF INTERMITTENT SAND FILTERS

Design Flow (MGD)	Design Hydraulic Loading Rate (MGAD)	Effective Size Sand (mm)	Cost With Federal Assistance ($/$10^6$ Gal)	Cost Without Federal Assistance ($/$10^6$ Gal)	Construction Cost Per Acre ($/Acre)
0.1	0.2	0.17	$236	$503	$144,194
1.0	0.4	0.17	$ 70	$179	$130,581
1.0	1.0	0.31, or 0.40, or 0.68	$ 45	$ 95	$142,648

to $70 per million gallons of filtrate with 75 percent federal assistance. However, this design will satisfy the State of Utah, effluent discharge requirements in every respect, except coliform concentrations.

Harris et al. (1975) estimated a total annual cost including operation and maintenance costs of $33 per million gallons filtrate with 75 percent federal assistance for a 1,892 m^3/d (0.5 MGD) sand filter system with a hydraulic loading rate of 5,612 $m^3/ha\cdot d$ (0.6 MGAD).

Estimated construction costs per hectare of filter vary from $58,355 per hectare ($144,194 per acre) for the 379 m^3/d (0.1 MGD) design flow to $52,846 per hectare ($130,581 per acre) for the 3,785 m^3/d (1.0 MGD) design flow. Harris et al. (1975) reported a construction cost of $41,114 per hectare ($101,592 per acre) of intermittent sand filter with a design flow of 1,892 m^3/d (0.5 MGD).

Lining the base and the embankments of the intermittent sand filters with vinyl to prevent infiltration and exfiltration represented more than 10 percent of the initial construction costs for all estimates. Constructing an intermittent sand filter on clay soil will require 85 percent to 95 percent compaction to prevent seepage and would eliminate the need to line an intermittent sand filter. Other methods of decreasing the construction cost of intermittent sand filters are to utilize the highest hydraulic loading rate that will achieve effluent requirements, utilize the available head, optimize the pumping requirements, and select a shape of intermittent sand filter system that will require minimum lengths of piping, and optimizing excavation and fill costs.

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APPENDIX A

TABULATION OF RESULTS

TABLE A-1. PERFORMANCE OF THE 0.17 MM EFFECTIVE SIZE SAND FILTER (FILTER NO. 6)

Filter Run Length No. 1: 280 consecutive days of operation, weeds removed, 90 consecutive days of operation (filter did not show any signs of plugging during the year-long study)
Hydraulic Loading Rate: 1871 m^3/ha·d (0.2 MGAD)
Application Rate: 0.048 m^3/sec (0.29 cfs)

Date	BOD_5 (mg/l)		COD (mg/l)		SS (mg/l)		VSS (mg/l)		NH_3-N (mg/l)		NO_2-N (mg/l)		NO_3-N (mg/l)		TKN (mg/l)		Total N_2 (mg/l)		Total-P (mg/l)		O-PO_4 (mg/l)		DO (mg/l)		Water Temp. (°C)		pH		Alkalinity (mg/l)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
August 15, 1975	9.8	3.7	-	-	44.9	23.8	33.3	2.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.8	6.9	21.2	23.0	-	-	-	-
18	11.5	0.5	31.7	11.5	34.3	5.7	24.4	0.9	0.943	0.069	0.190	0.011	0.523	3.840	-	-	-	-	2.09	2.49	1.51	2.60	8.1	6.9	20.3	21.5	8.9	8.3	-	-
21	12.8	1.1	36.3	12.2	50.1	3.9	36.0	0.6	0.192	0.040	0.101	0.081	0.286	1.7350	-	-	-	-	1.95	2.00	0.78	1.88	13.8	7.3	19.8	20.2	9.2	7.9	-	-
25	12.9	0.4	90.3	15.9	49.7	3.2	35.8	1.1	0.038	0.032	0.001	0.002	0.020	2.300	-	-	-	-	1.63	1.66	0.80	1.77	14.9	6.8	19.0	20.5	9.3	8.0	-	-
28	8.9	1.2	-	-	51.6	2.7	35.3	1.0	0.029	0.030	0.602	0.038	0.024	2.572	-	-	-	-	1.44	1.41	0.55	1.37	12.9	7.0	19.0	19.0	9.4	8.0	-	-
Monthly Ave.	11.2	1.4	52.8	13.2	46.1	7.9	33.0	1.2	0.300	0.040	0.229	0.033	0.214	2.610	-	-	-	-	1.78	1.89	0.91	1.91	11.9	7.0	19.9	20.8	9.2	8.0	-	-
September 2	6.3	0.6	46.7	9.9	33.2	1.4	22.5	0.6	0.063	0.009	0.004	0.002	0.034	4.080	-	-	-	-	1.48	1.41	0.72	1.38	9.3	7.2	19.2	20.0	9.1	8.3	-	-
9	6.5	0.5	61.8	8.8	26.7	1.8	21.4	0.5	0.106	0.014	0.008	0.006	0.086	3.483	-	-	-	-	1.33	1.20	0.69	1.16	13.2	7.1	19.0	19.1	9.1	8.0	-	-
11	9.7	0.4	89.6	5.5	49.7	1.6	44.6	0.8	0.931	0.048	0.000	0.000	0.028	2.766	-	-	-	-	1.64	1.20	0.76	1.13	14.5	8.7	19.2	19.5	9.3	8.7	-	-
15	7.9	0.5	73.0	18.3	29.6	2.2	23.4	1.1	0.090	0.059	0.013	0.006	0.067	2.361	-	-	-	-	1.51	0.97	0.94	0.99	11.5	6.9	20.0	20.0	9.0	7.8	-	-
18	7.5	0.8	-	-	35.0	3.2	24.0	0.5	0.652	0.040	0.034	0.005	0.131	1.901	-	-	-	-	1.62	1.02	1.09	0.99	10.8	7.9	17.9	18.0	9.0	8.2	-	-
24	6.5	1.1	66.6	8.0	26.3	1.3	15.4	0.6	0.778	0.036	0.029	0.021	0.156	3.360	-	-	-	-	1.19	1.00	0.91	1.06	18.0	8.8	17.2	17.9	9.1	7.9	-	-
29	4.4	1.2	46.8	-	17.7	1.3	9.2	0.6	1.139	0.023	0.033	0.001	0.193	2.504	-	-	-	-	1.08	0.88	1.07	0.94	11.8	7.5	16.0	17.5	9.0	8.0	-	-
Monthly Ave.	7.0	0.7	67.8	10.6	31.2	1.8	22.9	0.7	0.540	0.030	0.17	0.006	0.099	2.92	-	-	-	-	1.41	1.09	0.88	1.09	12.4	7.7	18.4	18.9	9.1	8.1	-	-
October 6	7.3	1.3	75.2	7.3	62.6	3.4	22.9	1.1	2.548	0.048	0.017	0.005	0.063	3.420	-	-	-	-	1.95	1.08	1.73	1.10	1.9	8.2	22.2	21.9	8.3	7.6	-	-
14	7.2	0.6	-	-	11.8	0.9	7.8	0.9	2.303	0.287	0.008	0.018	0.063	5.739	-	-	-	-	2.15	1.83	2.05	1.86	-	-	-	-	-	-	-	-
23	8.5	2.5	37.3	8.6	14.0	3.1	6.2	0.5	4.785	0.101	0.008	0.007	0.156	6.569	-	-	-	-	2.33	2.46	1.98	2.43	4.8	12.0	7.8	11.2	7.9	7.8	-	-
29	8.6	0.9	30.3	16.9	11.0	4.1	6.3	0.6	5.654	0.208	0.047	0.072	0.077	3.954	-	-	-	-	2.27	1.96	2.27	-	5.3	8.9	5.5	7.0	8.1	7.7	-	-
Monthly Ave.	7.9	1.3	47.7	10.9	25.1	2.9	10.8	0.8	3.690	0.210	0.020	0.026	0.090	4.850	-	-	-	-	2.17	1.84	1.92	1.80	4.0	9.7	11.8	13.4	8.1	7.7	-	-
November 5	4.3	0.8	30.1	3.4	14.4	6.3	6.5	1.8	4.782	0.085	0.027	0.004	0.077	3.811	7.7	3.3	7.8	7.1	2.33	2.36	2.15	2.31	4.0	8.7	9.0	8.0	7.8	7.4	294	279
12	5.0	1.2	28.6	5.0	8.8	2.1	4.0	0.5	5.657	0.072	0.021	0.003	0.067	5.029	9.2	1.2	9.3	6.2	2.53	2.50	2.45	2.38	6.6	10.8	5.2	7.2	8.3	8.3	304	282
19	2.6	1.5	23.8	5.7	3.2	0.4	3.2	0.4	6.375	0.156	0.021	0.041	0.065	6.410	8.4	7.6	8.5	14.0	2.34	2.38	2.34	2.48	7.4	9.2	4.0	6.0	8.2	8.1	301	276
26	3.7	0.9	24.5	4.7	5.0	3.0	2.4	0.8	4.849	0.925	0.029	0.049	0.099	6.681	8.0	9.4	8.1	16.0	2.29	2.20	2.09	2.11	9.3	11.0	5.0	6.3	8.1	7.9	337	302
Monthly Ave.	3.9	1.1	26.8	4.7	7.9	3.0	4.0	0.9	5.620	0.250	0.025	0.024	0.077	5.480	8.3	5.4	8.4	10.9	2.37	2.36	2.26	2.32	6.8	9.9	5.8	6.9	8.1	7.9	309	285
December 3	2.9	1.8	28.0	6.9	4.5	1.9	3.0	0.7	5.171	1.379	0.030	0.006	0.050	6.713	8.2	0.9	8.3	7.6	2.50	2.30	2.27	2.28	6.7	10.9	4.9	4.9	7.8	7.5	330	322
10	5.5	1.5	46.7	18.8	9.3	1.3	7.2	0.6	5.000	0.108	0.052	0.008	0.120	6.792	7.2	0.3	7.3	7.1	2.59	2.46	2.16	2.38	11.4	9.4	5.5	6.5	8.3	7.5	307	278
17	7.8	0.7	35.1	3.7	11.2	1.7	9.3	0.5	4.520	0.157	0.035	0.008	0.101	5.191	7.8	1.1	7.9	6.3	2.25	2.12	1.94	1.95	15.4	10.5	3.0	2.8	8.5	8.1	289	259
22	9.8	1.0	41.7	13.9	12.0	1.8	10.5	0.6	4.656	0.325	0.043	0.009	0.099	4.885	7.6	1.5	7.7	6.4	2.22	1.99	1.84	1.84	19.8	12.4	2.5	2.0	8.8	7.6	277	271
29	6.4	0.9	37.7	12.4	5.6	3.5	4.2	1.0	5.260	0.231	0.054	0.012	0.109	7.237	5.2	2.0	5.3	9.2	2.27	2.11	2.09	2.09	10.8	10.4	4.1	4.9	8.6	7.5	329	273
Monthly Ave.	6.5	1.2	37.8	11.1	8.5	2.0	6.8	0.7	4.840	0.440	0.043	0.019	0.096	6.160	7.2	1.2	7.3	7.4	2.36	2.19	2.06	2.11	12.8	10.7	4.0	4.2	8.4	7.6	306	281
January 7	13.5	1.5	37.8	13.7	16.9	1.6	14.9	0.8	6.144	0.844	0.048	0.013	0.102	4.167	7.8	0.7	7.9	4.9	2.33	2.09	2.15	2.05	11.2	10.8	4.0	3.5	8.4	8.3	315	274
14	14.7	1.6	45.7	11.1	21.3	1.9	19.0	1.1	5.075	0.459	0.033	0.009	0.138	2.939	8.0	1.2	8.1	4.1	2.68	2.68	2.51	2.68	6.4	9.6	4.5	3.5	8.7	8.0	260	290
21	11.3	1.7	48.8	12.4	17.4	2.4	16.0	0.5	5.682	0.428	0.030	0.019	0.042	3.010	9.7	1.0	9.7	3.0	2.87	2.55	2.59	2.57	1.4	10.1	1.5	1.5	8.6	7.9	322	305
28	9.5	1.0	44.1	10.3	7.1	1.2	6.5	0.4	5.828	1.024	0.004	0.018	0.010	4.596	9.3	2.3	9.3	6.9	2.75	2.55	2.58	2.54	0.7	8.2	2.0	1.5	8.6	8.6	332	306
Monthly Ave.	12.3	1.5	44.1	11.9	15.7	1.8	14.3	0.7	5.540	0.690	0.029	0.015	0.073	3.680	8.7	1.3	8.8	5.0	2.66	2.47	2.46	2.46	4.9	9.7	3.0	2.5	8.6	8.2	307	294
February 4	15.2	3.0	48.7	23.3	10.1	-	7.0	1.9	5.828	1.258	0.006	0.018	0.083	3.521	7.7	2.7	7.8	6.2	3.12	2.81	2.79	2.73	0.5	10.2	2.0	1.0	8.4	8.4	342	325
11	16.3	1.3	45.4	9.9	13.4	3.1	11.3	3.1	7.139	2.198	-	-	-	-	10.5	2.6	-	-	3.22	2.81	2.79	2.78	0.9	9.1	2.0	2.0	8.1	7.9	331	305
18	15.4	1.6	50.0	21.0	9.3	1.3	8.6	0.6	6.700	2.062	0.003	0.013	0.034	3.266	10.7	2.3	10.7	5.6	3.32	3.11	3.25	3.10	0.6	8.2	2.0	1.5	7.7	7.7	348	331
26	15.9	1.0	49.5	14.4	8.8	2.0	8.8	2.0	7.773	1.909	0.004	0.020	0.040	5.018	14.0	2.2	14.0	7.2	3.03	2.74	2.74	2.63	0.4	8.6	2.0	1.5	8.0	7.9	337	332
Monthly Ave.	15.7	1.7	48.6	17.1	10.5	2.1	8.9	1.9	6.860	1.860	0.004	0.017	0.052	3.940	10.7	2.5	10.8	6.4	3.17	3.02	2.89	2.81	0.6	9.0	2.0	1.5	8.0	8.0	340	323
March 3	13.8	1.5	48.4	11.0	8.9	1.2	6.4	0.9	8.516	1.371	0.002	0.070	0.025	7.045	10.2	2.9	10.2	9.9	3.34	2.55	3.03	2.55	0.5	8.9	2.0	1.0	8.1	7.7	339	303
10	21.4	2.3	61.6	17.5	8.5	0.8	-	-	8.031	2.231	0.002	0.015	0.022	3.747	11.4	3.5	11.4	7.2	3.47	3.08	3.17	3.10	0.4	9.2	3.0	2.0	8.0	7.8	-	312
17	20.6	1.1	66.4	10.4	7.9	1.1	7.0	0.5	8.375	1.447	0.000	0.009	0.028	1.671	10.9	2.4	10.9	4.0	3.48	3.19	2.69	2.64	0.6	7.8	2.5	4.5	7.7	7.4	318	315
23	22.3	1.0	55.2	8.5	8.5	0.6	7.5	0.5	6.948	0.988	0.000	0.035	0.011	7.791	11.0	0.9	11.0	8.7	3.10	2.70	3.27	3.16	0.4	8.4	2.5	4.5	7.7	7.5	317	317
Monthly Ave.	19.5	1.5	57.9	11.9	8.5	0.9	7.0	0.6	7.970	1.510	0.001	0.032	0.023	5.060	10.9	2.4	10.9	7.5	3.35	2.88	3.04	2.86	0.5	8.6	2.5	3.0	7.8	7.6	325	312
April 1	16.3	0.9	57.1	10.1	12.8	0.7	11.8	0.3	6.178	1.487	0.003	0.182	0.019	5.345	10.9	0.8	10.9	6.1	3.22	3.12	2.84	3.05	0.4	7.8	3.8	4.0	7.7	7.5	299	312
8	17.0	0.8	63.1	12.7	23.1	1.3	21.9	0.1	4.837	0.849	0.012	0.006	0.021	2.427	9.0	1.6	9.0	4.0	2.75	2.87	2.29	2.86	6.2	9.3	5.1	7.2	8.0	7.7	280	302
14	14.3	0.5	46.9	4.8	19.4	1.1	16.3	0.7	4.415	0.443	0.003	0.005	0.013	2.812	8.1	0.6	8.1	3.4	2.56	2.62	2.04	2.55	0.9	6.3	9.7	10.2	7.9	7.5	260	290
21	21.5	0.4	71.4	8.1	36.4	1.6	32.3	0.9	2.615	0.128	0.035	0.005	0.080	3.442	7.6	0.8	7.7	4.2	1.97	2.45	1.85	2.43	18.2	7.9	9.9	10.2	8.9	8.0	260	261
28	12.2	0.9	77.4	9.5	51.5	2.1	46.5	2.3	0.682	0.103	0.040	0.005	0.145	1.563	6.6	1.7	6.7	3.3	2.25	2.15	1.25	2.10	18.4	7.6	10.4	10.1	9.5	8.0	253	227
Monthly Ave.	16.3	0.7	63.2	9.0	28.6	1.4	25.8	0.9	3.740	0.600	0.019	0.004	0.0560	3.110	8.4	1.1	8.5	4.2	2.55	2.64	2.06	2.60	8.8	7.8	7.8	8.3	8.4	7.7	270	278
May 5	6.7	0.8	34.6	7.7	13.2	2.0	11.7	0.7	0.072	0.080	0.033	0.005	0.182	2.162	2.1	0.7	2.3	2.8	0.75	1.66	0.50	1.58	17.9	6.3	14.5	15.8	9.8	8.0	251	215
12	5.4	0.3	33.6	8.0	11.7	3.9	9.2	0.6	0.083	0.037	0.010	0.002	0.025	2.194	1.8	0.8	1.8	3.0	0.68	1.26	0.43	1.21	10.6	7.0	16.0	17.5	9.6	8.5	253	216
19	5.3	1.2	57.3	7.0	20.5	7.3	11.9	0.9	0.067	0.032	0.001	0.002	0.027	2.337	1.2	0.7	1.2	3.0	0.48	1.15	0.38	1.07	8.8	7.2	19.0	18.0	9.7	8.5	289	230
26	6.6	0.7	37.8	6.8	24.0	2.9	20.1	0.6	0.139	0.071	0.012	0.017	0.037	1.946	1.0	0.3	1.0	2.2	0.78	1.16	0.53	1.06	10.3	6.6	18.0	18.0	9.7	8.2	252	220
Monthly Ave.	6.0	0.8	40.8	7.4	17.4	4.0	13.2	0.7	0.090	0.060	0.014	0.007	0.0680	2.150	1.5	0.6	1.6	2.8	0.67	1.30	0.46	1.23	12.0	6.8	16.9	17.3	9.7	8.3	261	220
June 2	13.8	0.7	34.4	5.3	74.3	2.4	67.6	0.7	0.094	0.073	0.006	0.001	0.064	3.445	8.6	1.8	8.7	5.2	1.51	0.85	0.62	0.82	12.0	7.1	20.0	20.7	9.6	8.3	249	225
9	9.3	1.0	51.0	16.0	18.5	3.2	15.6	1.1	0.574	0.061	0.005	0.006	0.046	9.487	3.9	0.7	3.9	10.2	1.09	0.86	0.66	0.78	10.9	7.2	20.0	20.3	8.6	7.8	274	236
16	3.7	0.5	40.1	6.4	8.9	2.5	5.5	0.7	1.180	0.088	0.006	0.004	0.019	2.800	1.9	1.6	1.9	4.4	0.31	1.15	1.04	1.02	5.2	7.4	17.0	18.5	8.6	7.8	210	254
23	17.4	0.4	61.6	19.1	22.2	3.7	19.6	1.1	1.148	0.101	0.014	0.054	0.041	2.252	3.7	0.2	3.7	5.5	1.50	1.05	0.98	1.01	10.8	8.4	16.2	18.3	9.1	8.0	272	244
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monthly Ave.	11.1	0.7	46.8	11.7	31.0	3.0	27.1	0.9	0.750	0.080	0.008	0.017	0.040	5.250	4.5	1.1	4.5	6.4	1.10	0.97	0.82	0.91	9.8	7.5	18.3	19.5	9.0	8.0	256	261
July 7	20.8	0.8	135.5	-	64.8	2.5	62.4	1.2	0.112	0.044	0.008	0.002	0.064	4.108	6.9	1.0	7.0	5.1	1.76	1.16	0.51	1.11	19.4	5.5	23.9	24.2	9.5	7.9	247	212
14	14.6	0.7	64.3	15.0	22.4	2.6	18.2	0.7	1.100	0.069	0.016	0.003	0.035	5.969	4.2	0.5	4.2	6.5	1.74	1.40	1.01	1.25	8.5	8.1	23.0	24.9	9.0	8.1	234	217
21	12.7	0.9	74.1	22.1	20.8	1.3	18.3	0.9	1.082	0.053	0.071	0.003	0.033	2.529	4.4	0.8	4.4	3.3	1.63	1.26	0.94	1.22	9.7	6.0	23.0	23.8	9.4	7.6	269	212
28	19.8	0.4	88.9	20.1	35.9	1.4	31.9	0.8	1.247	0.059	0.010	0.002	0.028	4.010	6.5	0.6	6.5	4.6	1.76	1.23	0.95	1.16	4.0	6.6	23.0	24.5	9.2	7.4	203	238
Monthly Ave.	17.0	0.7	75.8	19.1	36.0	2.0	32.5	1.0	0.880	0.080	0.026	0.030	0.040	4.160	5.5	0.7	5.5	4.9	1.73	1.28	0.85	1.19	10.4	6.6	24.4	23.2	9.3	7.8	233	220
August 11	6.2	0.3	50.5	9.6	12.2	1.2	10.0	0.6	1.118	0.023	0.040	0.005	0.026	2.681	5.7	1.0	5.7	3.7	1.47	1.48	0.95	1.34	9.8	5.4	23.0	23.2	8.6	6.9	254	283
18	-	0.6	56.1	12.7	20.1	-	16.9	2.6	1.149	0.034	0.019	0.003	0.013	2.340	3.5	1.5	3.5	3.8	1.52	1.30	1.18	1.35	8.7	8.0	20.5	22.5	8.8	7.5	284	243
25	9.7	1.2	57.8	11.5	20.0	2.3	16.1	1.0	0.935	0.023	0.013	0.002	0.036	3.721	-	-	-	-	1.50	1.44	1.25	1.41	-	-	20.0	20.5	8.8	7.0	263	265
Monthly Ave.	8.0	0.8	54.1	11.2	16.1	1.8	14.3	1.7	1.030	0.030	0.144	0.003	0.025	2.910	4.6	1.3	4.6	4.2	1.50	1.40	1.13	1.37	6.7	6.7	21.2	22.1	8.7	7.1	267	264
Filter Run Ave.	10.9	1.1	50.5	11.3	23.0	2.7	17.8	1.0	3.153	0.440	0.041	0.015	0.076	4.005	6.9	2.2	7.0	6.2	2.05	1.93	1.65	1.88	8.5	8.3	12.1	15.5	8.7	7.9	286	271

TABLE A-2. PERFORMANCE OF THE 0.17 MM EFFECTIVE SIZE SAND FILTER (FILTER NO. 1)

Date	BOD$_5$ (mg/l)		COD (mg/l)		SS (mg/l)		VSS (mg/l)		NH$_3$-N (mg/l)		NO$_2$-N (mg/l)		NO$_3$-N (mg/l)		TKN (mg/l)		Total N$_2$ (mg/l)		Total-P (mg/l)		O-PO$_4$ (mg/l)		DO (mg/l)		Water Temp. (°C)		pH		Alkalinity (mg/l)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
Filter Run No. 1: 11 consecutive days of operation Hydraulic Loading Rate: 3742 m^3/ha·d (0.4 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)																														
August 15, 1975	9.8	1.1	-	-	44.9	2.3	33.3	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.8	6.7	21.2	21.8	-	-	-	-
18	11.5	1.1	31.7	12.0	34.3	1.9	24.4	0.8	0.943	0.097	0.190	0.003	0.523	2.660	-	-	-	-	2.09	1.96	1.51	2.04	8.1	6.6	20.3	22.0	8.9	9.3	-	-
21	12.8	1.4	36.3	13.9	50.1	3.7	36.0	2.4	0.192	0.068	0.101	0.006	0.286	1.892	-	-	-	-	1.95	1.71	0.78	1.51	13.8	6.8	19.8	20.8	9.2	8.0	-	-
25	12.9	2.5	90.3	29.3	49.7	8.7	35.8	7.7	0.038	0.097	0.001	0.010	0.020	1.060	-	-	-	-	1.63	1.57	0.80	1.66	14.9	5.9	19.0	20.5	9.3	8.0	-	-
Monthly Ave.	11.8	1.4	52.8	18.7	44.8	4.2	32.4	3.1	0.391	0.582	0.097	0.006	0.276	1.871	-	-	-	-	1.89	1.75	1.03	1.74	11.7	6.5	20.1	21.3	9.1	8.1	-	-
Filter Run Ave.	11.8	1.4	52.8	18.7	44.8	4.2	32.4	3.1	0.391	0.582	0.097	0.006	0.276	1.871	-	-	-	-	1.89	1.75	1.03	1.74	11.7	6.5	20.1	21.3	9.1	8.1	-	-
Filter Run Length No. 2: 36 consecutive days of operation																														
September 2	6.3	3.4	46.7	15.6	33.2	17.6	22.5	10.1	0.063	0.043	0.004	0.008	0.034	0.657	-	-	-	-	1.48	1.46	0.72	1.40	9.3	6.4	19.2	20.1	9.1	8.4	-	-
9	6.5	1.4	61.8	9.6	26.7	2.5	21.4	1.2	0.106	0.074	0.008	0.004	-	-	-	-	-	-	1.33	1.20	0.69	1.57	13.2	6.2	19.0	21.2	9.1	8.0	-	-
11	9.7	0.8	89.6	13.2	49.7	2.1	44.6	1.5	0.931	0.040	0.0	0.0	0.028	5.350	-	-	-	-	1.64	1.14	0.76	1.11	14.5	7.8	19.2	20.0	9.3	8.9	-	-
15	7.9	0.2	73.0	9.2	29.6	1.9	23.4	0.9	0.090	0.070	0.013	0.095	0.067	1.479	-	-	-	-	1.51	1.08	0.94	0.92	11.5	6.3	20.0	20.0	9.0	7.6	-	-
18	7.5	2.2	-	-	35.0	3.3	24.0	2.5	0.652	0.058	0.034	0.007	0.131	0.309	-	-	-	-	1.62	1.21	1.09	1.09	10.8	7.2	17.9	18.2	9.0	8.4	-	-
24	6.5	3.0	66.6	25.7	26.0	7.5	15.4	4.5	0.778	0.166	0.029	0.013	0.156	0.332	-	-	-	-	1.19	1.13	0.91	1.22	18.0	7.5	17.2	18.0	9.1	8.3	-	-
29	4.4	1.4	46.8	18.5	17.7	1.7	9.2	1.3	1.139	0.130	0.033	0.013	0.193	0.221	-	-	-	-	1.08	1.06	1.07	1.12	11.8	5.5	16.0	17.0	9.0	8.3	-	-
Monthly Ave.	7.0	1.8	64.1	15.3	31.2	5.2	22.9	3.1	0.620	0.081	0.017	0.007	0.102	1.381	-	-	-	-	1.41	1.18	0.88	1.20	12.7	6.7	18.4	19.2	9.1	8.3	-	-
Filter Run Ave.	7.0	1.8	64.1	15.3	31.8	5.2	22.9	3.1	0.620	0.081	0.017	0.007	0.102	1.381	-	-	-	-	1.41	1.18	0.88	1.20	12.7	6.7	18.4	19.2	9.1	8.3	-	-
Filter Run Length No. 3: 166 consecutive days of operation																														
November 19	2.6	2.9	23.8	13.2	3.2	1.1	3.2	1.1	5.657	4.031	0.021	0.021	0.065	3.393	8.4	5.2	8.5	8.6	2.32	1.89	2.34	2.23	7.4	9.3	4.0	7.0	8.2	7.8	301	281
26	3.7	1.4	24.5	17.4	5.0	6.8	2.4	1.0	6.375	4.187	0.029	0.035	0.099	4.154	8.0	4.5	8.1	8.7	2.29	2.04	2.09	2.00	9.3	10.4	5.0	6.0	8.1	7.8	337	317
Monthly Ave.	3.2	2.2	24.2	15.3	4.1	4.0	2.8	1.1	6.020	4.111	0.025	0.028	0.082	3.774	8.2	4.9	8.3	8.6	2.31	1.97	2.21	2.12	8.4	9.9	5.5	6.5	8.2	7.8	319	299
December 3	2.9	4.4	28.0	12.2	4.5	6.7	3.0	1.1	4.849	3.944	0.030	0.062	0.050	4.796	8.2	3.4	8.3	8.2	2.50	2.18	2.27	2.08	6.7	10.4	4.9	5.2	7.8	7.8	330	302
10	5.5	2.5	46.7	10.2	9.3	3.2	7.2	0.9	5.171	1.068	0.052	0.064	0.120	9.069	7.2	0.4	7.3	9.5	2.59	2.13	2.16	2.11	11.4	8.4	5.5	8.0	8.3	7.8	307	283
17	7.8	2.1	35.1	8.4	11.2	2.8	9.3	0.8	5.000	1.139	0.035	0.105	0.101	6.935	7.8	2.1	7.9	9.0	2.25	1.89	1.94	1.94	15.4	8.9	3.0	3.0	8.5	7.8	289	256
22	9.8	1.4	41.7	12.8	12.0	1.5	10.5	0.9	7.520	0.648	0.043	0.056	0.099	7.318	7.6	0.8	7.7	8.1	2.22	1.84	1.84	1.72	19.8	8.7	2.5	2.0	8.8	7.5	277	274
29	6.4	1.4	37.7	14.7	5.6	2.2	4.2	0.8	4.656	0.518	0.054	0.042	0.109	3.730	5.2	1.8	5.3	5.5	2.27	2.14	2.09	2.00	10.8	10.6	4.1	5.0	8.6	7.4	329	276
Monthly Ave.	6.5	2.4	37.8	11.7	8.5	3.3	6.8	0.9	4.840	1.460	0.043	0.066	0.096	6.370	7.2	1.7	7.3	8.1	2.36	2.04	2.06	1.97	12.8	9.4	4.0	4.6	8.4	8.1	306	278
January 7	13.5	2.1	37.8	15.6	16.9	1.8	14.9	1.2	5.260	0.844	0.048	0.037	0.102	7.932	7.8	0.5	7.9	8.4	2.33	2.06	2.15	2.05	11.2	10.4	4.0	4.0	8.4	8.2	315	296
14	14.7	2.5	45.6	13.8	21.3	2.1	19.8	1.3	6.144	0.191	0.033	0.016	0.138	3.156	8.0	2.1	8.1	5.3	2.68	2.53	2.51	2.34	6.4	8.6	4.5	3.0	8.7	8.4	260	296
21	11.3	4.4	48.8	17.0	17.4	2.1	16.0	1.3	5.075	2.301	0.030	0.037	0.042	2.474	9.7	4.9	9.7	7.5	2.87	2.65	2.59	2.59	1.4	6.7	1.5	1.5	8.6	7.8	322	325
28	9.5	4.2	44.1	19.0	7.1	2.1	6.5	1.5	5.682	3.244	0.004	0.024	0.010	2.249	9.3	7.0	9.3	9.2	2.75	2.74	2.58	2.69	0.7	7.8	2.0	1.5	8.6	8.6	332	320
Monthly Ave.	12.3	3.3	44.1	16.4	15.7	2.0	14.3	1.3	5.540	1.900	0.029	0.029	0.073	3.953	8.7	3.6	8.8	7.6	2.66	2.49	2.46	2.42	4.9	8.4	3.0	2.5	8.6	8.4	307	309
February 4	15.2	4.2	48.7	32.9	10.1	5.8	7.0	0.2	5.828	4.169	0.006	0.062	0.083	8.249	7.7	4.4	7.8	12.6	3.12	2.78	2.78	2.76	0.5	8.7	2.0	1.5	8.4	8.3	342	332
11	16.3	5.5	45.4	21.7	13.4	4.1	11.3	4.1	7.139	5.068	-	-	-	-	10.5	6.8	-	-	3.22	2.90	2.79	2.73	0.9	6.3	2.0	1.0	8.1	8.9	331	321
18	15.4	6.3	50.0	18.9	9.3	3.6	8.6	3.1	6.700	5.781	0.003	0.026	0.034	2.997	10.7	8.0	10.7	11.0	3.32	2.95	3.25	2.80	0.6	7.7	2.0	1.5	7.7	8.3	348	326
26	15.9	4.5	49.5	35.4	8.8	2.7	8.8	2.7	7.773	4.591	0.004	0.034	0.040	2.188	14.0	8.6	14.0	10.8	3.03	2.78	2.74	2.71	0.4	8.7	2.0	2.0	8.0	8.8	337	316
Monthly Ave.	15.7	5.1	48.4	27.2	10.4	4.1	8.9	2.5	6.860	4.900	0.004	0.041	0.052	4.492	10.7	7.0	10.8	11.5	3.17	2.85	2.89	2.75	0.6	7.6	2.0	1.5	8.0	8.2	340	324
March 3	13.8	4.2	48.4	19.6	8.9	3.4	6.4	3.4	8.516	5.888	0.002	0.016	0.025	5.032	10.2	6.3	10.2	11.3	3.34	2.51	3.03	2.46	0.5	4.8	2.0	2.0	8.1	7.7	339	315
10	21.4	7.4	61.4	29.4	8.5	2.5	-	-	8.031	6.870	0.002	0.007	0.022	0.358	11.4	8.7	11.4	9.1	3.47	3.31	3.17	3.07	0.4	4.2	3.0	2.5	7.8	7.7	-	-
17	20.6	5.2	66.4	22.9	7.9	3.2	7.0	2.7	8.375	6.472	0.0	0.012	0.028	0.343	10.9	9.6	10.9	9.9	3.48	3.50	2.69	2.29	0.6	5.5	2.5	4.6	7.7	7.7	318	327
23	22.3	3.7	55.2	17.6	8.5	2.3	7.5	2.0	6.948	5.562	0.0	0.049	0.011	0.907	11.0	7.9	11.0	8.8	3.10	2.50	3.27	3.24	0.4	7.2	2.5	5.0	7.7	7.6	317	320
Monthly Ave.	19.5	5.1	57.9	22.6	8.5	2.9	7.0	2.7	7.966	6.198	0.001	0.021	0.023	1.660	10.9	8.1	10.9	9.8	3.35	2.97	3.04	2.77	0.5	5.4	2.5	3.5	7.8	7.7	325	313
April 1	16.3	6.5	57.1	24.4	12.8	3.5	11.8	2.8	6.175	6.813	0.003	0.026	0.019	0.733	10.9	9.4	10.9	10.1	3.22	3.44	2.84	3.34	0.4	6.1	3.8	6.1	7.7	7.8	299	321
8	17.0	3.6	63.1	26.9	23.1	3.6	21.9	3.0	4.837	5.510	0.012	0.021	0.021	0.604	9.0	7.7	9.0	8.3	2.75	2.86	2.29	2.76	6.2	7.2	5.1	9.1	8.0	7.8	280	297
14	14.3	2.3	46.9	12.6	19.4	2.7	16.3	2.5	4.415	4.435	0.003	0.027	0.013	0.747	8.1	6.5	8.1	7.2	2.56	2.84	2.05	2.54	0.9	8.6	9.7	11.0	7.9	7.5	260	275
21	21.5	7.3	41.4	25.4	36.4	9.6	32.3	9.4	2.615	1.933	0.035	0.036	0.080	1.212	7.6	4.2	7.7	5.4	1.97	1.80	1.86	1.81	18.2	5.7	9.9	11.0	8.9	8.1	260	237
28	12.2	2.0	77.4	15.2	51.5	2.4	46.5	1.6	0.682	0.599	0.040	0.031	0.145	1.014	6.6	2.2	6.7	3.2	2.25	1.82	1.25	1.80	18.4	5.7	10.4	11.3	9.5	7.8	253	220
Monthly Ave.	16.3	4.3	63.2	20.9	28.6	4.4	25.8	3.9	3.738	3.861	0.019	0.028	0.056	0.862	8.4	5.9	8.5	6.8	2.55	2.55	2.06	2.45	8.8	6.7	7.8	9.7	8.4	7.8	270	270
Filter Run Ave.	12.9	3.8	47.5	19.1	13.8	3.4	11.7	2.2	5.701	3.607	0.021	0.037	0.064	3.462	9.0	5.1	9.0	8.5	2.75	2.51	2.44	2.42	6.2	7.8	4.2	4.8	8.3	8.0	309	297
Filter Run Length No. 4: 103 consecutive days of operation																														
May 19	5.3	1.1	57.3	24.4	20.5	8.4	11.9	2.0	0.067	0.058	0.001	0.006	0.027	2.079	1.2	0.7	1.2	2.8	0.48	0.71	0.38	0.61	8.8	5.8	19.0	20.0	9.7	8.3	289	211
26	6.6	1.2	37.8	14.8	24.0	4.5	20.1	1.6	0.139	0.071	0.012	0.002	0.037	1.263	1.0	0.8	1.0	2.1	0.78	0.74	0.53	0.61	10.3	6.3	18.0	18.4	9.7	8.0	252	196
Monthly Ave.	6.0	1.2	47.6	19.6	22.3	6.5	16.0	1.8	0.100	0.065	0.007	0.004	0.032	1.671	1.1	0.8	1.1	2.5	0.63	0.72	0.46	0.61	9.6	6.1	18.5	19.2	9.7	8.2	271	204
June 2	13.8	1.0	34.6	11.9	74.3	3.0	67.6	1.4	0.094	0.094	0.006	0.002	0.064	1.168	8.6	3.1	8.7	4.3	1.51	0.67	0.62	0.67	12.0	6.6	20.0	21.0	9.6	8.3	249	204
9	9.3	1.8	51.0	18.7	18.5	3.1	15.6	1.9	0.574	0.096	0.005	0.005	0.046	2.853	3.9	0.2	3.9	3.1	1.09	0.67	0.66	0.61	10.9	7.5	20.0	21.0	8.6	8.0	274	210
16	3.7	1.2	40.1	15.9	8.9	1.7	5.5	1.5	1.180	0.077	0.006	0.004	0.019	2.161	1.9	0.3	1.9	2.5	0.31	0.86	1.04	0.78	5.2	6.8	17.0	20.0	8.6	7.7	210	181
23	17.4	1.2	61.6	17.2	22.2	1.3	19.6	1.0	1.148	0.063	0.014	0.003	0.041	2.820	3.7	0.6	3.7	3.4	1.50	1.03	0.98	0.06	10.8	7.9	16.2	18.0	9.1	8.0	272	244
30	10.2	0.8	61.0	15.6	14.6	1.6	13.9	0.9	0.920	0.068	0.028	0.004	0.028	2.470	3.6	1.9	3.6	4.4	1.75	1.14	1.17	1.08	10.3	7.1	23.1	25.0	9.1	8.0	263	212
Monthly Ave.	10.9	1.2	49.6	15.8	27.7	2.1	24.5	1.4	0.780	0.086	0.012	0.003	0.040	2.294	4.3	1.2	4.3	3.5	1.12	0.86	0.90	0.64	9.8	7.2	19.3	21.0	9.0	8.0	254	210
July 7	20.8	1.6	135.5	19.8	64.8	2.5	62.4	1.9	0.112	0.091	0.008	0.010	0.064	1.190	6.9	1.2	7.0	2.4	1.76	1.17	0.51	1.08	19.4	5.6	23.9	25.3	9.5	7.8	247	189
14	14.6	1.4	64.3	18.7	22.4	3.1	18.2	2.3	1.100	0.088	0.016	0.016	0.035	3.480	4.2	1.4	4.2	4.9	1.74	1.47	1.01	1.26	8.5	7.7	23.0	25.8	9.0	8.1	234	234
21	12.7	2.2	74.1	22.8	20.8	3.5	18.3	3.4	1.082	0.099	0.071	0.006	0.033	3.280	4.4	0.9	4.4	4.2	1.63	1.28	0.94	1.18	9.7	5.0	23.0	26.0	9.4	7.5	249	242
28	19.8	2.3	88.9	15.4	35.9	5.8	31.9	5.5	1.247	0.083	0.010	0.011	0.028	3.120	6.5	1.7	6.5	4.8	1.76	1.29	0.95	1.22	4.0	6.0	23.0	24.0	9.2	7.3	203	269
Monthly Ave.	17.0	1.8	90.2	19.2	17.0	3.7	32.5	3.3	0.880	0.100	0.026	0.011	0.040	2.768	5.5	1.3	5.5	4.1	1.73	1.30	0.85	1.19	10.4	6.1	23.2	25.3	9.3	7.7	233	234
August 4	4.5	0.5	51.3	14.3	8.2	0.3	6.7	0.2	3.090	0.184	0.003	0.027	0.028	4.090	5.1	0.6	5.1	4.7	2.33	1.69	1.76	1.69	2.3	5.6	22.5	25.0	8.3	7.0	263	251
11	6.2	0.4	50.5	11.8	12.2	1.2	10.0	0.6	1.180	0.024	0.040	0.008	0.026	2.980	5.7	1.1	5.7	4.1	1.47	1.25	0.95	1.30	9.8	4.6	23.0	25.0	8.6	7.0	254	277
18	-	0.1	54.1	12.0	20.1	0.3	-	-	1.149	0.062	0.019	0.003	0.013	2.210	3.5	0.5	3.5	2.7	1.53	1.36	1.18	1.18	8.7	8.1	20.5	23.2	8.8	7.4	284	280
25	9.7	0.8	57.8	11.8	20.0	1.0	16.1	0.6	0.935	0.060	0.013	0.020	0.036	6.096	-	-	-	-	1.50	1.55	1.25	1.41	-	-	20.0	22.5	8.8	7.2	263	288
Monthly Ave.	6.8	0.6	53.4	12.5	15.1	0.7	11.0	0.7	1.550	0.100	0.019	0.015	0.026	3.843	4.8	0.7	4.8	4.5	1.70	1.48	1.29	1.40	6.9	6.1	21.5	23.9	8.6	7.2	266	274
Filter Run Ave.	11.06	1.2	61.2	16.3	20.8	2.7	22.7	1.9	0.921	0.091	0.017	0.008	0.0135	2.750	4.3	1.1	4.3	3.7	1.4	1.1	1.0	1.0	9.3	6.5	20.8	22.7	9.1	7.7	254	233

TABLE A-3. PERFORMANCE OF THE 0.31 MM EFFECTIVE SIZE SAND FILTER (FILTER NO. 3)

Date	BOD_5 (mg/l)		COD (mg/l)		SS (mg/l)		VSS (mg/l)		NH_3-N (mg/l)		NO_2-N (mg/l)		NO_3-N (mg/l)		TKN (mg/l)		Total N_2 (mg/l)		Total-P (mg/l)		O-PO_4 (mg/l)		Water Temp. (°C)		DO (mg/l)		pH		Alkalinity (mg/l)	
	inf.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.	app.	eff.
Filter Run No. 1: 45 consecutive days without plugging Hydraulic Loading Rate: 9354 m^3/ha·d (1.0 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)																														
June 30	10.2	5.0	61.0	40.0	14.6	9.6	13.9	4.2	0.920	0.882	0.028	0.041	0.028	0.160	3.6	2.3	3.6	2.5	1.75	0.81	1.17	0.54	23.1	23.0	10.3	8.1	9.1	8.9	263	228
Monthly Ave.	10.2	5.0	61.0	40.0	14.6	9.6	13.9	4.2	0.920	0.882	0.028	0.041	0.028	0.160	3.6	2.3	3.6	2.5	1.75	0.81	1.17	0.54	23.1	23.0	10.3	8.1	9.1	8.9	263	228
July 7	20.8	11.2	135.5	71.2	64.8	18.8	62.4	15.5	0.112	0.527	0.008	0.098	0.064	0.100	6.9	3.7	7.0	3.8	1.76	1.03	0.51	0.61	23.9	23.7	19.4	6.5	9.5	8.9	247	202
14	14.6	7.3	64.3	50.3	22.4	14.1	18.2	8.5	1.100	0.970	0.016	0.073	0.035	0.120	4.2	3.1	4.2	3.2	1.74	1.41	1.01	0.91	23.0	23.0	8.5	9.0	9.0	8.8	234	220
21	12.7	8.1	74.1	51.9	20.8	12.8	18.3	8.9	1.082	0.406	0.071	0.071	0.033	0.190	4.4	2.3	4.4	2.5	1.63	1.30	0.94	0.92	23.0	22.0	9.7	7.1	9.4	9.0	249	257
28	19.8	9.2	88.9	79.9	35.9	29.2	31.9	26.6	1.247	0.881	0.010	0.080	0.028	0.290	6.5	4.5	6.5	4.8	1.76	1.44	0.95	0.82	23.0	23.0	4.0	5.7	9.2	9.0	203	231
Monthly Ave.	17.0	9.2	90.2	63.3	36.0	18.7	32.5	15.3	0.885	0.696	0.026	0.065	0.040	0.175	5.5	3.4	5.5	3.6	1.73	1.62	0.85	0.82	23.2	22.9	10.4	6.7	9.3	8.9	233	228
August 4	4.5	5.0	51.3	43.2	8.2	7.7	6.7	2.2	3.090	1.314	0.003	0.053	0.028	0.250	5.1	3.3	5.1	3.6	2.33	2.30	1.76	2.14	22.5	21.5	2.3	6.6	8.3	7.7	263	248
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monthly Ave.	4.5	5.0	51.3	43.2	8.2	7.7	6.7	2.2	3.090	1.314	0.003	0.053	0.028	0.250	5.1	3.3	5.1	3.6	2.33	2.30	1.76	2.14	22.5	21.5	2.3	6.6	8.3	7.7	263	248
Filter Run Ave.	13.8	7.8	78.9	56.1	27.8	15.4	25.2	11.7	1.252	0.833	0.023	0.070	0.036	0.185	5.1	3.2	5.1	3.4	1.65	1.30	1.06	0.99	23.1	22.7	9.0	6.9	9.1	8.7	243	231
Filter Run No. 2: 14 consecutive days without plugging Application Rate: 0.008 m^3/sec (0.29 cfs)																														
August 18	-	-	54.1	39.9	20.1	21.0	16.9	3.3	1.149	0.270	0.019	0.038	0.013	0.366	3.5	2.1	3.5	2.5	-	-	1.18	1.73	20.5	22.0	8.7	7.9	8.8	7.7	284	295
25	9.7	6.1	57.8	35.4	20.0	10.2	16.1	3.0	0.935	0.214	0.013	0.092	0.036	1.120	-	-	-	-	1.50	1.87	1.25	1.76	20.0	19.0	-	-	8.8	7.6	263	266
Monthly Ave.	9.7	6.1	56.0	37.7	20.1	15.5	16.5	3.2	1.042	0.242	0.016	0.065	0.025	0.743	3.5	2.1	3.5	2.5	1.50	1.87	1.22	1.75	20.3	20.5	8.7	7.9	8.8	7.7	274	270
Filter Run Ave.	9.7	6.1	56.0	37.7	20.1	15.5	16.5	3.2	1.042	0.242	0.016	0.065	0.025	0.743	3.5	2.1	3.5	2.5	1.50	1.87	1.22	1.75	20.3	20.5	8.7	7.9	8.8	7.7	274	281

TABLE A-4. PERFORMANCE OF THE 0.40 MM EFFECTIVE SIZE SAND FILTER (FILTER NO. 2)

Date	BOD_5 (mg/l)		COD (mg/l)		SS (mg/l)		VSS (mg/l)		NH_3-N (mg/l)		NO_2-N (mg/l)		NO_3-N (mg/l)		TKN (mg/l)		N_2 Dolomite (mg/l)		Total-P (mg/l)		O-PO_4 (mg/l)		DO (mg/l)		Water Temp (°C)		pH		Alkalinity (mg/l)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
Filter Run No. 1: [illegible] consecutive days of operation Hydraulic Loading Rate: [illegible] Application Rate: [illegible]																														
August 15, 1975	9.8	3.8	-	-	66.9	12.5	33.3	3.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	[illegible]	7.3	20.5	20.5	-	-	-	-
18	11.5	6.0	30.7	20.7	56.3	10.7	24.6	5.5	0.963	1.000	0.190	0.282	0.523	1.770	5.6	2.9	5.0	6.7	2.09	1.60	1.54	1.36	[illegible]	7.0	20.3	20.3	[illegible]	[illegible]	-	-
Monthly Ave.	10.7	5.0	30.7	20.7	59.6	11.6	28.9	4.7	0.963	1.000	0.190	0.282	0.523	1.770	5.6	2.9	5.0	6.7	2.09	1.60	1.54	1.36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-
Filter Run Ave.	10.7	5.0	30.7	20.7	59.6	11.6	28.9	4.7	0.963	1.000	0.190	0.282	0.523	1.770	5.6	2.9	5.0	6.7	2.09	1.60	1.54	1.36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-
Filter Run No. 2: 37 consecutive days of operation Hydraulic Loading Rate: [illegible]																														
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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TABLE A-5. PERFORMANCE OF THE 0.40 MM EFFECTIVE SIZE SAND FILTER (FILTER NO. 5)

Date	BOD_5 (mg/l)		COD (mg/l)		SS (mg/l)		VSS (mg/l)		NH_3-N (mg/l)		NO_2-N (mg/l)		NO_3-N (mg/l)		TKN (mg/l)		Total N (mg/l)		Total-P (mg/l)		O-PO_4 (mg/l)		DO (mg/l)		Water Temp. (°C)		pH		Alkalinity (mg/l)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
Filter Run No. 1: 3 consecutive days of operation Hydraulic Loading Rate: 28,062 m^3/ha·d (3.0 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)																														
August, 15, 1975	9.8	6.5	-	-	44.9	83.0	33.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.8	7.3	21.2	21.0	-	-	-	-
Monthly Ave.	9.8	6.5	-	-	44.9	83.0	33.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.8	7.3	21.2	21.0	-	-	-	-
Filter Run Ave.	9.8	6.5	-	-	44.9	83.0	33.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.8	7.3	21.2	21.0	-	-	-	-
Filter Run No. 2: 7 consecutive days of operation Hydraulic Loading Rate: 18,708 m^3/ha·d (2.0 MGAD)																														
August 28	8.9	7.2	-	-	51.6	27.4	35.3	0.3	0.029	0.216	0.002	0.030	0.026	0.038	-	-	-	-	1.44	0.92	0.55	0.45	12.9	7.4	19.0	19.1	9.4	9.2	-	-
Monthly Ave	8.9	7.2	-	-	51.6	27.4	35.3	0.3	0.029	0.216	0.002	0.030	0.026	0.038	-	-	-	-	1.44	0.92	0.55	0.45	12.9	7.4	19.0	19.1	9.4	9.2	-	-
September 2	6.3	8.2	46.7	50.4	33.2	39.8	22.5	13.1	0.063	0.037	0.004	0.069	0.034	0.052	-	-	-	-	1.48	1.70	0.72	1.26	9.3	6.2	19.2	17.3	9.1	8.5	-	-
Monthly Ave	6.3	8.2	46.7	50.4	33.2	39.8	22.5	13.1	0.063	0.037	0.004	0.069	0.034	0.052	-	-	-	-	1.48	1.70	0.72	1.26	9.3	6.2	19.2	17.3	9.1	8.5	-	-
Filter Run Ave.	7.6	7.7	46.7	50.4	42.4	33.6	28.9	10.7	0.046	0.084	0.303	0.050	0.029	0.445	-	-	-	-	1.46	1.31	0.64	0.86	11.1	6.8	19.1	18.2	9.3	8.9	-	-
Filter Run No. 3: 10 consecutive days of operation																														
September 15	7.9	5.2	73.0	30.8	29.6	21.0	23.4	4.6	0.080	0.090	0.013	0.065	0.067	0.174	-	-	-	-	1.51	1.11	0.94	0.87	11.5	7.7	20.0	18.7	9.0	9.0	-	-
18	7.5	4.8	-	-	35.0	16.7	26.0	5.4	0.652	0.470	0.034	0.122	0.131	0.360	-	-	-	-	1.62	1.15	1.09	0.93	10.8	8.7	17.9	17.0	9.0	8.9	-	-
24	6.5	4.2	66.6	45.7	26.3	20.1	15.4	6.4	0.778	0.086	0.029	0.366	0.156	0.040	-	-	-	-	1.19	2.71	0.91	2.75	10.0	8.3	17.2	18.2	9.1	8.0	-	-
29	4.6	3.7	46.8	29.5	17.7	11.2	9.2	3.4	1.139	0.100	0.033	0.065	0.193	2.810	-	-	-	-	1.08	2.14	1.07	2.10	11.8	6.2	16.0	16.0	9.0	8.8	-	-
Monthly Ave	6.6	6.5	62.1	30.0	26.7	17.3	10.0	5.0	0.664	0.191	0.027	0.150	0.137	2.041	-	-	-	-	1.35	1.78	1.00	1.66	13.0	7.2	17.8	17.5	9.0	8.7	-	-
Filter Run Ave.	6.6	6.5	62.1	30.0	26.7	17.3	10.0	5.0	0.664	0.191	0.027	0.150	0.137	2.041	-	-	-	-	1.35	1.78	1.00	1.66	13.0	7.2	17.8	17.5	9.0	8.7	-	-
Filter Run No. 4: 6 consecutive days of operation following 22 days of resting and no scraping																														
October 21	8.5	10.9	-	-	14.0	19.2	6.2	3.2	5.124	1.327	0.008	0.060	0.156	12.030	-	-	-	-	2.33	2.93	1.98	2.95	4.8	9.5	7.8	9.2	7.9	7.5	-	-
Monthly Ave.	8.5	10.9	-	-	14.0	19.2	6.2	3.2	5.124	1.327	0.008	0.060	0.156	12.030	-	-	-	-	2.33	2.93	1.98	2.95	4.8	9.5	7.8	9.2	7.9	7.5	-	-
Filter Run Ave.	8.5	10.9	-	-	14.0	19.2	6.2	3.2	5.124	1.327	0.008	0.060	0.156	12.030	-	-	-	-	2.33	2.93	1.98	2.95	4.8	9.5	7.8	9.2	7.9	7.5	-	-
Filter Run No. 5: 168 consecutive days of operation																														
November 12	5.0	3.6	20.1	23.4	8.8	22.1	4.0	2.9	6.702	3.175	0.021	0.032	0.067	1.194	9.2	6.0	9.3	8.0	2.53	2.76	2.65	2.67	6.6	11.5	5.2	6.0	8.3	8.2	304	300
19	2.6	6.7	23.8	25.3	3.2	1.2	3.2	1.2	5.657	4.781	0.021	0.027	0.065	0.353	8.6	7.0	8.5	7.4	2.34	2.65	2.36	2.31	7.4	11.0	4.0	4.5	8.2	8.3	301	306
26	3.7	5.6	26.5	22.9	5.0	7.1	2.4	1.7	6.375	5.146	0.029	0.038	0.099	0.608	8.0	9.3	8.1	9.9	2.29	2.24	2.08	2.16	10.4	15.0	5.8	5.5	8.1	8.0	337	327
Monthly Ave.	9.7	4.6	25.6	23.9	5.7	10.1	3.2	1.9	5.600	4.370	0.024	0.032	0.077	0.718	8.5	7.7	8.6	8.4	2.38	2.48	2.29	2.31	7.8	10.5	4.7	5.3	8.2	8.2	314	310
December 3	2.9	3.9	28.0	26.1	4.5	5.7	3.0	1.9	4.849	3.017	0.030	0.031	0.050	0.309	8.2	7.7	8.3	8.0	2.50	2.58	2.27	2.24	6.7	10.4	4.9	4.9	7.8	8.0	330	325
10	5.5	6.3	46.7	33.0	9.3	8.5	7.7	6.2	5.171	4.380	0.052	0.065	0.120	0.578	7.2	3.0	7.3	3.6	2.59	2.46	2.16	2.23	11.4	9.7	5.5	5.0	8.3	8.0	307	301
17	7.8	8.0	35.1	26.0	11.2	6.0	9.3	5.1	5.080	2.478	0.035	0.044	0.101	1.946	7.8	4.6	7.9	9.5	2.25	2.20	1.94	2.14	15.7	11.4	3.0	1.5	8.5	8.8	289	299
22	9.8	8.2	61.7	30.1	12.0	11.0	10.5	7.5	4.520	2.072	0.063	0.061	0.089	1.153	7.6	6.1	7.7	7.3	2.22	2.07	1.86	1.83	19.8	11.8	2.5	1.0	8.8	8.4	277	291
29	6.6	7.4	37.7	34.0	5.6	3.0	4.2	1.9	4.656	3.411	0.054	0.065	0.109	0.532	5.2	5.2	5.3	5.7	2.27	2.23	2.09	2.09	10.8	12.5	4.1	5.0	8.6	8.2	329	287
Monthly Ave.	6.5	6.5	37.0	31.6	8.5	7.2	6.8	4.5	4.840	3.070	0.063	0.041	0.096	0.904	7.2	5.3	7.3	6.2	2.36	2.29	2.06	2.10	12.8	11.2	4.0	3.5	8.4	8.3	306	301
January 7	13.5	13.1	37.0	35.9	16.9	13.9	16.9	11.5	5.380	3.680	0.048	0.032	0.102	1.136	7.8	6.4	7.9	7.5	2.33	2.32	2.15	2.16	11.2	11.0	6.0	3.6	8.6	8.4	315	304
14	16.7	10.6	45.7	35.3	21.3	9.3	19.8	7.8	6.164	4.765	0.033	0.015	0.130	0.637	8.0	7.1	8.1	7.7	2.68	2.67	2.51	2.67	6.4	11.8	4.5	4.0	8.7	8.4	260	309
21	11.3	10.4	48.8	30.2	17.6	8.4	16.0	6.3	5.075	3.980	0.030	0.016	0.062	1.169	9.7	5.7	9.7	6.8	2.87	2.93	2.59	2.85	1.4	10.3	1.5	0.5	8.6	8.0	322	315
28	9.5	9.6	44.1	30.4	7.1	5.7	6.5	4.6	5.602	3.967	0.004	0.011	0.010	0.421	9.3	7.0	9.3	7.4	2.75	2.92	2.58	2.71	0.7	8.8	2.0	1.5	8.6	8.6	332	320
Monthly Ave.	12.3	10.9	44.1	37.5	15.7	9.3	16.3	7.6	5.540	3.950	0.029	0.018	0.073	0.846	8.7	6.6	8.8	7.4	2.66	2.71	2.46	2.59	6.9	10.5	3.8	2.4	8.6	8.4	307	312
February 6	15.2	12.9	48.7	39.6	10.1	9.9	7.0	6.1	5.828	4.439	0.006	0.009	0.003	0.594	7.7	7.1	7.8	7.7	3.12	3.09	2.78	2.84	0.5	10.2	2.0	1.5	8.4	8.4	342	325
11	16.3	13.7	65.4	41.3	13.4	10.0	11.3	10.0	7.138	6.752	-	-	-	-	10.5	7.5	-	-	3.22	3.15	2.79	2.94	0.9	8.1	2.0	1.0	8.1	8.1	331	322
18	15.4	16.3	50.0	32.3	9.3	8.1	8.6	7.2	6.780	5.156	0.003	0.011	0.034	0.539	10.7	8.3	10.7	8.8	3.32	3.27	3.25	3.18	0.6	9.7	2.0	2.5	7.7	7.6	348	333
26	15.9	8.9	49.5	38.5	8.8	6.6	8.8	6.4	7.773	8.081	0.004	0.013	0.040	0.303	14.0	11.8	14.0	12.2	3.03	2.99	2.76	2.81	0.4	8.4	2.0	2.0	8.0	8.1	337	344
Monthly Ave.	15.7	13.0	48.6	37.4	10.5	8.2	8.9	6.9	6.880	5.610	0.004	0.011	0.052	0.505	10.7	8.7	10.8	9.2	3.17	3.12	2.88	2.94	0.6	9.1	2.0	1.8	8.0	8.1	340	332
March 3	13.8	9.7	48.6	35.4	8.9	5.6	6.4	5.2	8.516	6.083	0.002	0.011	0.025	1.293	10.2	7.6	10.2	8.7	3.34	3.26	3.03	3.08	0.5	9.4	2.0	1.0	8.1	7.6	338	323
10	21.6	11.5	61.6	38.6	8.5	6.1	-	-	8.031	5.633	0.002	0.015	0.022	0.632	11.4	7.8	11.4	8.4	3.47	3.61	3.17	3.38	0.6	8.5	3.0	2.0	7.8	7.6	-	-
17	20.6	11.6	66.6	32.7	7.9	5.5	7.0	5.1	8.375	7.081	0.008	0.011	0.020	0.379	10.9	8.6	10.9	9.0	3.48	3.28	2.69	2.43	0.6	3.9	2.5	2.2	7.7	7.6	310	312
23	22.3	9.0	59.2	31.9	8.5	6.6	7.5	6.6	6.948	4.137	0.000	0.050	0.011	1.003	11.0	7.5	11.0	9.4	3.10	2.60	3.27	3.15	0.4	6.6	2.5	3.0	7.7	7.2	317	306
Monthly Ave.	19.5	10.5	57.9	36.7	8.5	6.9	7.0	5.0	7.970	5.860	0.001	0.024	0.023	1.047	10.9	7.8	10.9	8.8	3.35	3.28	3.04	2.98	0.5	6.6	2.5	2.1	7.8	7.5	325	313
April 1	16.3	23.3	57.1	51.1	12.8	11.3	11.0	10.7	6.175	5.777	0.003	0.031	0.019	0.572	10.9	10.4	10.9	11.0	3.22	3.74	2.84	3.39	0.4	3.5	3.8	7.2	7.7	7.3	299	322
Monthly Ave.	16.3	23.3	57.1	51.1	12.8	11.3	11.0	10.7	6.175	5.777	0.003	0.031	0.019	0.572	10.9	10.4	10.9	11.0	3.22	3.74	2.84	3.39	0.4	3.5	3.8	7.2	7.7	7.3	299	322
Filter Run Ave.	12.5	9.6	63.2	71.7	10.1	8.0	8.5	5.6	6.120	4.529	0.021	0.027	0.064	0.817	9.2	7.3	9.3	8.1	2.80	2.80	2.55	2.61	5.3	9.3	3.2	3.1	8.2	8.1	317	314
Filter Run No. 6: 42 consecutive days of operation																														
April 16	16.3	12.5	46.9	41.0	19.6	12.2	16.3	11.0	4.615	3.042	0.003	0.040	0.013	0.428	8.1	6.3	8.1	6.7	2.36	2.40	2.05	1.98	0.9	6.1	9.7	9.8	7.9	9.8	260	252
21	21.5	17.3	71.4	56.5	38.6	23.2	32.3	21.9	2.615	1.909	0.035	0.071	0.080	1.190	7.6	5.9	7.7	7.1	1.97	2.03	1.86	2.03	10.2	9.8	9.9	10.1	8.9	8.6	280	246
28	12.2	7.7	77.6	77.5	51.5	20.0	46.5	27.7	0.482	0.444	0.040	0.075	0.165	0.037	6.8	4.8	6.7	5.6	2.25	1.76	1.25	1.46	10.4	7.0	10.4	10.2	9.5	9.1	253	234
Monthly Ave.	16.0	12.5	65.2	57.9	35.8	21.1	31.7	20.2	2.571	1.897	0.026	0.062	0.070	0.819	7.4	4.1	7.5	6.5	2.26	2.06	1.72	1.82	12.5	7.6	10.0	10.0	8.8	9.2	258	244
May 5	6.7	6.0	36.6	26.2	13.2	3.0	11.7	2.5	0.072	0.062	0.033	0.004	0.182	1.301	2.1	1.6	2.3	2.9	0.75	1.19	0.58	1.38	17.9	7.3	16.5	7.3	9.8	9.0	251	221
12	5.6	3.0	33.6	38.0	11.7	2.0	9.2	2.0	0.083	0.070	0.010	0.001	0.025	0.706	1.8	1.3	1.8	2.0	0.68	0.94	0.43	0.79	10.6	7.6	16.0	14.8	9.6	9.2	253	217
19	5.3	2.6	57.3	22.0	20.5	4.0	11.9	2.8	0.009	0.060	0.001	0.002	0.027	0.735	1.2	1.0	1.2	1.8	0.68	1.04	0.38	1.07	8.8	5.5	19.0	18.0	9.7	9.1	280	219
26	6.6	5.4	37.8	37.7	26.0	12.5	20.1	11.2	0.139	0.516	0.012	0.008	0.037	0.284	1.0	2.1	1.0	2.4	0.70	1.28	0.53	0.84	10.3	2.9	18.0	17.7	9.7	9.0	252	223
Monthly Ave.	6.0	5.7	40.8	28.2	17.3	5.5	13.2	4.6	0.080	0.180	0.014	0.019	0.067	0.762	1.5	1.3	1.6	2.3	0.67	1.11	0.46	0.95	12.0	5.0	16.9	16.5	9.7	9.1	261	220
Filter Run Ave.	10.6	8.6	51.3	40.9	25.2	13.3	21.1	11.3	1.193	0.916	0.019	0.037	0.072	0.788	4.0	2.6	4.2	4.1	1.35	1.52	1.08	1.32	12.3	6.6	13.9	12.6	9.3	9.2	260	230
Filter Run No. 7: 23 consecutive days of operation																														
June 16	3.7	3.7	40.1	28.6	8.9	2.8	5.9	1.2	1.180	1.196	0.006	0.007	0.019	0.283	1.9	1.6	1.9	1.9	0.31	1.31	1.04	1.10	5.2	7.8	17.0	15.0	8.6	9.0	210	231
23	17.4	5.4	61.6	39.4	22.2	3.6	19.6	3.3	1.140	0.880	0.014	0.015	0.041	0.380	3.7	1.5	3.7	1.9	1.58	1.31	0.98	0.87	10.8	7.7	16.2	16.2	9.1	9.0	272	284
30	10.2	4.4	61.0	37.6	16.6	3.1	13.9	2.3	0.920	0.530	0.028	0.033	0.028	0.380	3.6	1.0	3.6	2.2	1.75	1.65	1.17	1.15	10.3	7.5	23.1	23.0	9.1	8.9	283	248
Monthly Ave.	10.4	4.5	54.2	34.5	19.2	3.1	13.0	2.1	1.080	0.890	0.016	0.019	0.029	0.341	3.1	1.7	3.1	2.0	1.28	1.37	1.06	1.04	8.8	7.7	18.8	18.1	8.8	9.0	260	245
July 7	20.8	11.0	135.5	91.5	64.0	33.4	62.6	31.9	0.112	0.015	0.000	0.001	0.064	0.160	6.9	5.9	7.0	6.1	1.76	1.58	0.51	0.81	19.4	5.2	23.9	23.5	9.5	9.1	267	228
Monthly Ave.	20.8	11.0	135.5	91.5	64.0	33.4	62.6	31.9	0.112	0.015	0.000	0.001	0.064	0.160	6.9	5.9	7.0	6.1	1.76	1.58	0.51	0.81	19.4	5.2	23.9	23.5	9.5	9.1	267	228
Filter Run Ave.	13.0	6.1	74.5	48.8	27.6	10.7	25.4	9.6	0.830	0.671	0.014	0.015	0.038	0.288	4.1	2.8	4.1	3.0	1.34	1.43	0.92	0.98	11.5	7.1	20.1	19.5	9.0	9.0	248	241
Filter Run No. 8: 37 consecutive days of operation Hydraulic Loading Rate: 9354 m^3/ha·d (1.0 MGAD) Application Rate: 0.008 m^3/sec (0.29 cfs)																														
July 21	12.7	6.2	-	-	20.8	6.6	10.3	5.6	1.002	0.570	0.071	0.016	0.033	0.010	4.6	2.3	4.4	3.1	1.63	1.00	0.94	1.38	9.7	6.2	23.0	23.0	9.4	8.8	260	257
28	19.8	7.4	88.9	60.1	35.9	16.0	31.9	16.0	1.347	0.988	0.010	0.027	0.028	0.520	6.5	3.5	6.5	4.0	1.76	1.50	0.95	0.90	4.0	6.0	23.0	24.0	9.2	9.0	201	275
Monthly Ave.	16.3	6.8	88.9	60.1	28.4	11.3	25.0	10.5	1.150	0.880	0.041	0.022	0.031	0.665	5.5	2.9	5.5	3.6	1.70	1.80	0.95	1.15	6.9	5.1	23.0	23.5	9.3	8.9	226	266
August 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	6.7	3.8	50.5	37.6	12.2	1.8	10.0	1.2	1.118	0.296	0.040	0.030	0.028	1.450	3.7	3.3	3.7	4.0	1.47	1.40	0.95	1.31	9.8	5.2	23.0	22.7	8.6	7.9	256	257
18	-	-	54.1	35.3	20.1	0.0	10.9	2.1	1.140	0.283	0.019	0.009	0.013	0.170	3.5	1.4	3.5	1.6	1.53	2.13	1.10	2.02	8.7	6.4	20.5	22.5	8.8	7.3	284	265
25	9.7	3.9	57.8	40.3	20.0	5.1	16.1	3.1	0.935	0.637	0.013	0.023	0.036	1.390	-	-	-	-	-	-	1.25	1.72	-	-	20.0	20.5	8.8	7.3	283	284
Monthly Ave.	8.0	3.9	54.1	37.7	17.4	5.0	14.3	1.7	1.030	0.370	0.024	0.021	0.025	0.903	4.6	2.4	4.6	3.0	1.50	1.71	1.13	1.60	9.3	5.8	21.2	18.8	8.7	7.5	267	263
Filter Run Ave.	12.2	5.6	62.0	45.6	21.8	7.5	18.6	5.2	1.078	0.542	0.031	0.021	0.027	0.862	5.0	2.7	5.1	3.5	1.60	1.66	1.06	1.47	8.1	5.5	21.9	20.7	8.9	8.1	251	265

TABLE A-6. PERFORMANCE OF THE 0.68 MM EFFECTIVE SIZE SAND FILTER (FILTER NO. 3)

Date	BOD_5 (mg/l)		COD (mg/l)		SS (mg/l)		VSS (mg/l)		NH_3-N (mg/l)		NO_2-N (mg/l)		NO_3-N (mg/l)		TKN (mg/l)		Total N_2 (mg/l)		Total-P (mg/l)		O-PO_4 (mg/l)		DO (mg/l)		Water Temp. (°C)		pH		Alkalinity (mg/l)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
Filter Run No. 1: 46 consecutive days of operation Hydraulic Loading Rate: 14,031 m^3/ha·d (1.5 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)																														
August 25, 1975	12.9	4.5	90.3	38.2	49.7	16.0	35.8	4.8	0.038	0.023	0.001	0.003	0.020	0.160	-	-	-	-	1.63	0.44	0.80	0.41	14.9	7.4	19.0	18.5	9.3	8.7	-	-
28	8.9	5.7	-	-	51.6	21.2	35.3	10.2	0.029	0.389	0.602	0.006	0.024	0.013	-	-	-	-	1.44	0.82	0.55	0.39	12.9	7.7	19.0	18.7	9.4	9.1	-	-
Monthly Ave.	10.9	5.1	90.3	38.2	50.7	18.6	35.6	7.5	0.035	0.206	0.301	0.005	0.022	0.087	-	-	-	-	1.54	0.63	0.68	0.40	13.9	7.6	19.0	19.1	9.4	8.9	-	-
September 2	6.3	6.8	46.7	36.1	33.2	27.8	22.5	6.9	0.063	0.048	0.004	0.380	0.034	0.587	-	-	-	-	1.48	0.55	0.72	0.55	9.3	7.9	19.2	18.0	9.1	9.0	-	-
9	6.5	6.5	61.8	36.4	26.7	30.0	21.4	7.0	0.106	0.109	0.008	0.429	0.086	0.920	-	-	-	-	1.33	1.20	0.69	0.83	13.2	7.2	19.0	18.8	9.1	8.9	-	-
11	9.7	6.1	89.6	42.1	49.7	29.3	44.6	12.6	0.931	0.195	0.000	0.144	0.028	0.200	-	-	-	-	1.64	0.14	0.76	0.77	14.5	9.0	19.2	18.4	9.3	9.0	-	-
15	7.9	6.5	73.0	38.2	29.6	20.2	23.4	6.5	0.090	0.079	0.013	0.156	0.067	0.342	-	-	-	-	1.51	1.02	0.94	0.85	11.5	6.9	20.0	18.0	9.0	8.7	-	-
18	7.5	6.1	-	-	35.0	19.9	24.0	7.1	0.652	0.522	0.034	0.173	0.131	0.425	-	-	-	-	1.62	1.23	1.09	0.98	10.8	8.1	17.9	17.2	9.0	8.8	-	-
24	6.5	5.7	66.6	47.5	26.3	11.8	15.4	4.9	0.778	0.439	0.029	0.158	0.156	0.413	-	-	-	-	1.19	0.92	0.91	0.90	18.0	9.2	17.2	17.2	9.1	9.0	-	-
29	4.4	4.0	46.8	55.4	17.7	7.5	9.2	2.5	1.139	1.383	0.033	0.116	0.193	0.362	-	-	-	-	1.08	1.02	1.07	1.36	11.8	7.9	16.0	16.0	9.0	8.9	-	-
Monthly Ave.	7.0	5.8	64.1	42.6	31.2	20.9	22.9	6.8	0.620	0.460	0.017	0.227	0.099	0.464	-	-	-	-	1.41	0.87	0.88	0.89	12.7	8.0	18.4	17.7	9.1	8.9	-	-
October 6	7.3	5.8	75.2	39.9	62.6	12.9	22.9	4.2	2.548	0.883	0.017	0.168	0.063	4.105	-	-	-	-	1.95	3.20	1.73	2.28	1.9	8.3	22.2	22.9	8.3	7.8	-	-
Monthly Ave.	7.3	5.8	75.2	39.9	62.6	12.9	22.9	4.2	2.548	0.883	0.017	0.168	0.063	4.105	-	-	-	-	1.95	3.20	1.73	2.28	1.9	8.3	22.2	22.9	8.3	7.8	-	-
Filter Run Ave.	7.8	5.7	68.8	41.7	38.2	19.6	25.4	6.7	0.695	0.452	0.074	0.173	0.087	0.753	5.7	5.7	5.8	6.5	1.49	0.94	0.84	0.78	11.9	8.0	18.9	18.5	9.1	8.8	-	-
Filter Run No. 2: [illegible] consecutive days of operation Hydraulic Loading Rate: 9354 m^3/ha·d (1.0 MGAD)																														
November 3	3.0	4.3	30.1	25.8	14.4	6.5	6.5	1.4	5.654	5.211	0.027	0.013	0.077	0.175	7.7	7.7	7.8	7.9	2.33	2.31	2.15	2.20	4.0	9.2	9.0	8.5	7.8	7.9	294	296
12	5.0	4.2	28.6	24.9	8.8	8.4	4.0	1.9	4.782	5.853	0.021	0.014	0.067	0.157	9.2	9.0	9.3	9.2	2.53	2.71	2.45	2.24	6.6	10.6	5.2	5.3	8.3	8.2	304	303
19	2.6	4.8	23.8	27.7	3.2	1.6	3.2	1.6	5.657	5.700	0.021	0.017	0.065	0.224	8.4	6.0	8.5	6.2	2.34	2.61	2.34	2.37	7.4	10.6	4.0	4.5	8.2	8.2	301	301
26	3.7	4.8	24.5	22.1	5.0	7.9	2.4	1.5	6.375	6.083	0.029	0.030	0.099	0.287	8.0	9.1	8.1	9.4	2.29	2.23	2.09	2.07	9.3	12.0	5.0	6.1	8.1	8.1	337	333
Monthly Ave.	3.9	4.5	26.8	25.1	7.9	6.1	4.0	1.6	5.620	5.710	0.025	0.019	0.077	0.211	8.3	8.0	8.4	8.2	2.37	2.47	2.26	2.22	6.8	10.6	5.8	6.1	8.1	8.1	309	308
December 3	2.9	5.6	28.0	23.5	4.5	9.4	3.0	3.0	4.849	5.905	0.030	0.023	0.050	0.399	8.2	7.3	8.3	7.7	2.50	2.72	2.27	2.23	6.7	10.8	4.9	5.5	7.8	7.9	330	322
10	5.5	5.3	46.7	48.3	9.3	5.6	7.2	3.7	5.171	3.312	0.052	0.050	0.120	0.378	7.2	6.0	7.3	6.4	2.59	2.33	2.16	2.31	11.4	10.5	5.5	8.0	8.3	8.1	307	301
17	7.8	4.9	35.1	22.7	11.2	3.4	9.3	2.3	5.000	4.891	0.035	0.044	0.101	0.245	7.8	6.8	7.9	7.0	2.25	2.02	1.94	2.02	15.4	11.7	3.0	2.8	8.5	8.4	289	286
22	9.8	4.8	41.7	35.4	12.0	7.9	10.5	5.8	4.520	2.016	0.043	0.051	0.099	0.276	7.6	6.4	7.7	6.7	2.22	2.01	1.84	1.83	19.8	11.8	2.5	3.0	8.8	8.5	277	298
29	6.4	4.6	37.7	31.1	5.6	3.9	4.2	2.3	4.656	3.887	0.054	0.062	0.109	0.399	5.2	5.5	5.3	5.9	2.27	2.17	2.09	2.03	10.8	13.0	4.1	5.0	8.6	8.4	329	297
Monthly Ave.	6.5	5.0	37.8	32.2	8.5	6.0	6.8	3.4	4.840	7.630	0.043	0.046	0.096	0.339	7.2	6.4	7.3	6.7	2.36	2.25	2.06	2.08	12.8	11.6	4.0	4.9	8.4	8.3	306	308
January 7	13.5	9.1	37.8	36.7	16.9	8.6	14.9	6.9	5.260	4.740	0.048	0.046	0.102	0.337	7.8	7.2	7.9	7.5	2.33	2.33	2.15	2.11	11.2	11.4	4.0	3.5	8.4	8.5	315	308
14	14.7	14.1	45.7	43.0	21.3	21.1	19.8	17.5	6.144	4.979	0.033	0.011	0.138	0.519	8.0	7.9	8.1	8.4	2.68	2.65	2.51	2.65	6.4	10.0	4.5	4.0	8.7	8.5	260	313
21	11.3	13.6	48.8	46.5	17.4	17.0	16.0	12.4	5.075	4.557	0.030	0.007	0.042	0.298	9.7	7.9	9.7	8.1	2.87	3.07	2.59	2.73	1.4	10.6	1.5	1.0	8.6	8.1	322	317
28	9.5	7.9	44.1	37.8	7.1	6.1	6.5	4.6	5.682	5.041	0.004	0.011	0.010	0.131	9.3	10.8	9.3	10.9	2.75	2.85	2.58	2.71	0.7	10.0	2.0	1.5	8.6	8.6	332	321
Monthly Ave.	12.3	11.2	44.1	41.0	15.7	13.2	14.3	10.3	5.540	4.830	0.029	0.019	0.073	0.321	8.7	8.5	8.8	8.8	2.66	2.73	2.46	2.55	4.9	10.5	3.0	2.5	8.6	8.4	307	315
February 4	15.2	11.8	48.7	40.0	10.1	11.4	7.0	5.6	5.828	5.249	0.006	0.007	0.083	0.162	7.7	7.3	7.8	7.5	3.12	3.06	2.78	2.65	0.5	10.2	2.0	1.5	8.4	8.4	342	321
11	16.3	12.5	45.6	44.1	13.4	10.7	11.3	10.7	7.139	6.103	-	-	-	-	10.5	7.4	-	-	3.22	3.18	2.79	2.89	0.9	10.0	2.0	2.5	8.1	8.6	331	328
18	15.4	10.9	50.0	33.4	9.3	9.1	8.6	7.3	6.700	5.918	0.003	0.010	0.034	0.412	10.7	8.7	10.7	9.1	3.32	3.32	3.25	3.28	0.6	11.6	2.0	1.5	7.7	8.1	348	331
26	15.9	9.6	49.5	42.1	8.8	6.1	8.8	5.6	7.773	6.773	0.004	0.021	0.040	0.308	14.0	10.5	14.0	10.8	3.03	2.97	2.74	2.87	0.4	10.6	2.0	3.0	8.0	8.2	337	349
Monthly Ave.	15.7	11.2	48.4	39.9	10.4	9.3	8.9	7.3	6.860	6.010	0.004	0.013	0.052	0.294	10.7	8.5	10.8	8.8	3.17	3.13	2.89	2.92	0.6	10.6	2.0	2.1	8.0	8.3	340	332
March 3	13.8	15.0	48.4	40.5	8.9	8.4	6.6	6.9	8.516	7.810	0.002	0.015	0.025	0.353	10.2	9.3	10.2	9.7	3.34	3.23	3.03	3.11	0.5	9.8	2.0	2.0	8.1	7.9	339	327
10	21.4	17.6	61.4	45.9	8.5	6.6	-	-	8.031	7.421	0.002	0.012	0.022	0.153	11.4	9.9	11.4	10.1	3.47	3.33	3.17	3.10	0.4	8.2	3.0	2.5	7.8	7.9	-	-
17	20.6	14.7	66.4	37.8	7.9	6.9	7.0	5.7	8.375	7.656	0.000	0.009	0.028	0.120	10.9	10.3	10.9	10.4	3.48	3.29	2.69	2.66	0.6	7.6	2.5	4.6	7.7	7.9	318	318
23	22.3	17.1	55.2	45.8	8.5	5.2	7.5	5.2	6.948	7.108	0.000	0.005	0.011	0.031	11.0	10.6	11.0	10.6	3.10	2.90	3.27	3.19	0.4	7.8	2.5	3.0	7.7	7.7	317	314
Monthly Ave.	19.5	16.1	57.9	42.5	8.5	6.8	7.0	5.9	7.970	7.500	0.001	0.010	0.023	0.164	10.9	10.0	10.9	10.2	3.35	3.19	3.04	3.01	0.5	8.4	2.5	3.0	7.8	7.8	325	320
April 1	16.3	11.4	57.1	38.5	12.8	7.1	11.8	6.8	6.175	6.175	0.003	0.016	0.019	0.050	10.9	10.9	10.9	11.0	3.22	3.17	2.84	2.94	0.4	7.9	3.8	3.9	7.7	7.7	299	301
8	17.0	13.6	63.1	42.3	23.1	13.1	21.9	12.2	4.837	4.531	0.012	0.035	0.021	0.104	9.0	8.0	9.0	8.1	2.75	2.67	2.29	2.44	6.2	8.8	5.1	6.5	8.0	8.0	280	282
14	14.3	8.8	46.9	37.3	19.4	11.3	16.3	10.0	4.415	3.831	0.003	0.027	0.013	0.306	8.1	7.2	8.1	7.3	2.36	2.65	2.03	2.17	0.9	8.1	9.7	10.2	7.9	10.2	260	258
21	21.5	17.3	71.4	51.5	36.4	25.2	32.3	21.5	2.615	2.104	0.035	0.042	0.080	0.476	7.6	6.0	7.7	7.1	1.97	2.00	1.86	1.89	18.2	9.0	9.9	10.1	8.9	8.8	260	248
28	12.2	6.2	77.4	53.3	51.5	25.1	46.5	22.6	0.682	0.591	0.040	0.026	0.145	0.542	6.6	6.5	6.7	7.0	2.25	1.63	1.25	1.28	18.4	8.6	10.4	10.8	9.5	9.1	253	234
Monthly Ave.	16.3	11.5	63.2	44.6	28.6	16.4	25.8	14.6	3.740	3.450	0.019	0.029	0.054	0.296	8.4	7.7	8.5	8.0	2.55	2.41	2.06	2.15	8.8	8.5	7.8	8.3	8.4	8.8	270	265
May 5	6.7	4.6	34.6	22.6	13.2	3.5	11.7	2.4	0.072	0.091	0.033	0.005	0.182	0.532	2.1	1.4	2.3	1.9	0.75	0.93	0.30	0.78	17.9	7.7	14.5	7.7	9.8	9.3	251	221
12	5.4	4.1	33.6	24.0	11.7	3.4	9.2	2.2	0.083	0.085	0.010	0.002	0.025	0.131	1.8	1.6	1.8	1.7	0.68	0.64	0.43	0.50	10.6	7.9	16.0	16.0	9.6	9.6	253	252
Monthly Ave.	6.1	4.4	34.1	23.3	12.5	3.5	10.5	2.3	0.080	0.090	0.022	0.004	0.104	0.332	2.0	1.5	2.1	1.8	0.71	0.79	0.46	0.64	14.3	7.8	15.3	11.9	9.7	9.5	252	237
June 2	13.8	14.6	34.4	36.5	-	-	67.6	56.3	0.094	0.077	0.006	0.001	0.064	0.932	8.0	6.0	8.1	6.9	1.51	1.42	0.62	0.65	12.0	8.2	20.0	20.2	9.6	9.5	249	253
9	9.3	5.3	51.0	35.7	18.5	5.8	15.6	4.8	0.574	0.500	0.005	0.006	0.046	0.211	3.9	0.9	3.9	1.1	1.09	2.98	0.66	0.71	10.9	8.6	20.0	20.2	8.6	9.5	274	261
Monthly Ave.	11.6	10.0	42.7	36.1	18.5	5.8	41.6	30.6	0.330	0.289	0.006	0.004	0.055	0.572	6.3	3.5	6.4	4.1	1.30	2.20	0.64	0.68	11.5	8.4	20.0	20.2	9.1	9.5	262	257
Filter Run Ave.	11.6	8.2	44.9	36.2	15.8	11.2	13.7	8.6	4.920	5.060	0.021	0.021	0.066	0.298	8.3	7.4	8.4	7.7	2.49	2.51	2.18	2.22	7.0	9.8	6.1	6.2	8.4	8.5	300	298

TABLE A-7. PERFORMANCE OF THE 0.68 MM EFFECTIVE SIZE SAND FILTER (FILTER NO. 4)

Date	BOD_5 (mg/l)		COD (mg/l)		SS (mg/l)		VSS (mg/l)		NH_3-N (mg/l)		NO_2-N (mg/l)		NO_3-N (mg/l)		TKN (mg/l)		Total N_2 (mg/l)		Total-P (mg/l)		O-PO_4 (mg/l)		Water Temp. (°C)		DO (mg/l)		pH		Alkalinity (mg/l)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
Filter Run No. 1: 11 consecutive days of operation Hydraulic Loading Rate: 28,062 m^3/ha·d (3.0 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)																														
August 25, 1975	12.9	2.9	90.3	78.7	49.7	19.3	35.8	8.8	0.038	0.088	0.001	0.001	0.020	0.090	-	-	-	-	1.63	0.71	0.80	0.51	19.0	19.0	14.9	7.2	9.3	9.0	-	-
28	8.9	5.7	-	-	51.6	29.0	35.3	14.1	0.029	1.049	0.602	0.011	0.024	0.011	-	-	-	-	1.44	0.92	0.55	0.50	19.0	19.0	12.9	7.5	9.4	9.0	-	-
Monthly Ave.	10.9	4.3	90.3	78.7	50.7	24.2	35.6	11.5	0.021	0.570	0.302	0.006	0.022	0.010	-	-	-	-	1.54	0.81	0.68	0.51	19.0	19.0	13.9	7.4	9.4	9.0	-	-
September 2	6.3	11.9	46.7	39.8	33.2	57.8	22.5	16.7	0.063	0.169	0.004	0.638	0.034	1.310	-	-	-	-	1.48	0.55	0.72	0.89	19.2	16.9	9.1	4.9	9.1	8.8	-	-
Monthly Ave.	6.3	11.9	46.7	39.8	33.2	57.8	22.5	16.7	0.063	0.169	0.004	0.638	0.034	1.310	-	-	-	-	1.48	0.55	0.72	0.89	19.2	16.9	9.3	4.9	9.1	8.8	-	-
Filter Run Ave.	9.4	6.8	68.5	59.3	44.9	35.4	31.2	13.2	0.043	0.435	0.203	0.217	0.026	0.443	-	-	-	-	1.21	0.84	0.69	0.63	19.1	18.3	12.4	6.5	9.3	8.9	-	-
Filter Run No. 2: 23 consecutive days of operation Hydraulic Loading Rate: 18,071 m^3/ha·d (2.0 MGAD)																														
September 18	7.5	6.3	-	-	35.0	71.9	24.0	9.4	0.652	0.478	0.034	0.373	0.131	3.674	-	-	-	-	1.62	1.27	1.09	0.88	17.9	17.5	10.8	8.6	9.0	8.8	-	-
24	6.5	4.8	66.6	44.2	26.1	16.4	15.4	5.6	0.778	0.862	0.029	0.158	0.156	1.112	-	-	-	-	1.19	1.02	0.91	0.96	17.2	16.0	18.0	9.8	9.1	9.0	-	-
29	4.4	3.7	46.8	32.6	17.7	11.3	9.2	5.2	1.139	0.848	0.033	0.139	0.193	0.318	-	-	-	-	1.08	1.01	1.07	1.04	16.0	15.9	11.8	8.6	9.0	9.0	-	-
Monthly Ave.	6.1	4.9	56.7	38.4	26.3	33.2	16.2	6.7	0.860	0.730	0.032	0.223	0.160	1.701	-	-	-	-	1.30	1.10	1.03	0.96	16.6	16.5	13.5	9.0	9.0	8.9	-	-
October 6	7.3	7.5	75.2	38.2	62.6	22.8	22.9	4.9	2.548	0.823	0.017	0.214	0.063	5.561	-	-	-	-	1.95	1.83	1.73	2.33	22.2	22.0	1.9	8.3	8.3	7.8	-	-
Monthly Ave.	7.3	7.5	75.2	38.2	62.6	22.8	22.9	4.9	2.548	0.823	0.017	0.214	0.063	5.561	-	-	-	-	1.95	1.83	1.73	2.33	22.2	22.0	1.9	8.3	8.3	7.8	-	-
Filter Run Ave.	6.4	5.6	62.9	38.3	35.4	30.6	17.9	6.3	1.282	0.753	0.028	0.221	0.136	2.668	-	-	-	-	1.46	1.28	1.21	1.30	18.0	17.9	10.6	8.8	8.8	8.6	-	-
Filter Run No. 3: 19 consecutive days of operation following 19 days of resting and no scraping																														
November 3	4.3	5.3	30.1	66.5	16.4	18.7	6.5	2.6	5.654	3.961	0.027	0.022	0.077	1.542	7.7	5.9	7.8	7.4	2.33	2.55	2.15	2.39	9.0	6.5	4.0	9.8	7.8	7.7	294	292
12	5.0	3.2	28.6	25.3	8.8	4.9	4.0	0.0	4.782	5.040	0.021	0.013	0.067	0.463	9.2	7.3	9.3	7.8	2.53	2.31	2.45	2.39	5.2	7.5	6.6	10.2	8.3	8.3	304	301
Monthly Ave.	4.7	4.3	29.4	45.9	11.6	11.8	5.3	1.3	5.218	4.501	0.024	0.018	0.072	1.003	8.5	6.6	8.6	7.6	2.43	2.43	2.30	2.39	7.1	7.0	5.3	10.0	8.1	8.0	299	297
Filter Run Ave.	4.7	4.3	29.4	45.9	11.6	11.8	5.3	1.3	5.218	4.501	0.024	0.018	0.072	1.003	8.5	6.6	8.6	7.6	2.43	2.43	2.30	2.39	7.1	7.0	5.3	10.0	8.1	8.0	299	297
Filter Run No. 4: 152 consecutive days of operation																														
November 26	3.7	5.2	24.5	24.4	5.0	6.9	2.4	0.3	6.375	6.708	0.029	0.024	0.099	0.289	8.0	7.0	8.1	7.3	2.29	2.23	2.08	2.14	5.0	8.5	9.3	14.3	8.1	8.1	337	337
Monthly Ave.	3.7	5.2	24.5	24.4	5.0	6.9	2.4	0.3	6.375	6.708	0.029	0.024	0.099	0.289	8.0	7.0	8.1	7.3	2.29	2.23	2.08	2.14	5.0	8.5	9.3	14.3	8.1	8.1	337	337
December 3	2.9	5.5	28.0	23.5	4.5	5.0	3.0	1.9	4.849	6.617	0.030	0.021	0.050	0.245	8.2	7.9	8.3	8.1	2.50	2.53	2.27	2.29	4.9	7.5	6.7	10.8	7.8	8.0	330	332
10	5.5	5.0	46.7	30.6	9.3	7.4	7.2	3.0	5.171	4.188	0.052	0.046	0.120	0.364	7.2	6.4	7.3	6.8	2.59	2.30	2.16	2.15	5.5	6.5	11.4	10.2	8.3	8.3	307	307
17	7.8	4.3	35.1	24.5	11.2	4.0	9.3	2.9	5.000	4.826	0.035	0.043	0.101	0.354	7.8	6.7	7.9	7.1	2.25	2.14	1.94	2.02	3.0	2.2	15.4	11.8	8.5	8.3	289	272
22	9.8	6.8	41.7	37.6	12.0	8.8	10.5	7.6	4.520	2.043	0.043	0.049	0.099	0.421	7.6	7.3	7.7	7.7	2.22	2.04	1.84	1.85	2.5	1.0	19.8	11.8	8.8	8.5	277	301
29	6.4	4.2	37.7	31.8	5.6	4.9	4.2	2.6	4.656	4.008	0.054	0.057	0.109	0.356	5.2	5.7	5.3	6.1	2.27	2.17	2.09	2.08	4.1	3.0	10.8	10.7	8.6	8.7	329	304
Monthly Ave.	6.5	5.2	37.8	29.6	8.5	6.0	6.8	3.6	4.840	4.340	0.043	0.043	0.096	0.348	7.2	6.8	7.3	7.1	2.36	2.24	2.06	2.08	4.0	4.0	12.8	11.1	8.4	8.4	306	303
January 7	13.5	10.4	37.8	35.9	16.9	11.4	14.9	9.7	5.260	4.827	0.068	0.045	0.102	0.365	7.8	7.1	7.9	7.5	2.33	2.44	2.15	2.11	4.0	3.5	11.2	12.0	8.4	8.5	315	315
14	14.7	15.6	65.7	40.7	21.3	24.4	19.8	21.3	6.144	4.873	0.033	0.011	0.138	0.842	8.0	7.0	8.1	7.8	2.68	2.62	2.51	2.61	4.5	4.0	6.4	9.8	8.7	8.5	260	321
21	11.3	14.3	68.8	48.0	17.4	19.0	16.0	16.9	5.075	4.576	0.030	0.008	0.062	0.375	9.7	7.8	9.7	8.1	2.87	3.09	2.59	2.64	1.5	1.0	1.4	9.4	8.6	8.0	322	324
28	9.5	8.6	44.1	30.8	7.1	6.3	6.5	4.9	5.682	5.289	0.004	0.010	0.010	0.085	9.3	10.3	9.3	10.4	2.75	2.63	2.58	2.67	2.0	2.0	0.7	9.8	8.6	6.6	332	323
Monthly Ave.	12.3	12.2	44.1	38.9	15.7	15.3	14.3	12.7	5.560	4.890	0.029	0.019	0.073	0.417	8.7	8.1	8.8	8.5	2.66	2.69	2.46	2.49	3.0	2.6	4.9	10.3	8.6	8.4	307	321
February 4	15.2	16.6	68.7	68.1	10.1	15.6	7.0	7.4	5.828	5.037	0.006	0.010	0.083	0.541	7.7	8.2	7.8	8.7	3.12	3.06	2.78	2.68	2.0	2.5	0.5	9.2	8.4	8.4	342	325
11	16.3	15.6	65.6	56.7	13.4	14.9	11.3	14.9	7.139	6.238	-	-	-	-	10.5	10.4	-	-	3.22	3.22	2.79	2.91	2.0	1.5	0.9	8.3	8.1	8.6	331	329
18	15.4	9.7	50.0	66.6	9.3	15.1	8.6	13.2	6.700	6.521	0.003	0.015	0.034	0.101	10.7	10.6	10.7	10.7	3.32	3.27	3.25	3.18	2.0	2.0	0.6	11.2	7.7	8.1	348	334
26	15.9	9.8	69.5	61.3	8.8	6.7	8.8	6.2	7.773	7.114	0.004	0.017	0.060	0.179	16.0	13.9	16.0	16.1	3.03	3.02	2.74	2.75	2.0	2.0	0.4	9.1	8.0	8.1	337	337
Monthly Ave.	15.7	12.6	68.4	68.2	10.5	13.0	8.9	10.4	6.860	6.230	0.004	0.016	0.052	0.276	10.7	10.8	10.8	11.1	3.17	3.14	2.89	2.88	2.0	2.0	0.6	9.5	8.0	8.3	340	331
March 3	13.8	10.7	68.4	43.9	8.9	7.2	6.4	6.9	8.516	8.127	0.002	0.011	0.025	0.265	10.2	9.6	10.2	9.7	3.36	3.25	3.03	3.00	2.0	1.5	0.5	10.7	8.1	8.0	339	334
10	21.4	12.7	61.4	37.9	8.5	5.7	-	-	8.031	6.634	0.002	0.014	0.022	0.443	11.4	9.7	11.4	9.7	3.67	3.68	3.17	3.55	3.0	2.5	0.4	9.6	7.8	7.8	-	-
17	20.6	15.0	66.4	34.6	7.9	5.0	7.0	5.0	8.375	7.868	0.0	0.009	0.028	0.119	10.9	10.2	10.9	10.3	3.68	3.39	2.69	2.72	2.5	3.8	0.6	7.7	7.7	7.7	318	316
23	22.3	15.2	55.2	61.7	8.5	5.9	7.5	5.9	6.948	7.369	0.0	0.006	0.011	0.032	11.0	10.1	11.0	10.1	3.10	2.93	3.27	3.21	2.5	3.0	0.4	7.3	7.7	7.7	317	315
Monthly Ave.	19.5	13.4	57.9	39.5	8.5	6.1	7.0	5.9	7.971	7.500	0.001	0.010	0.023	0.215	10.9	9.8	10.9	10.0	3.35	3.31	3.04	3.12	2.5	2.7	0.5	8.8	7.8	7.8	325	320
April 1	16.3	12.6	57.1	37.8	12.8	7.5	11.8	6.9	6.175	6.394	0.003	0.013	0.019	0.046	10.5	10.3	10.9	10.3	3.22	3.12	2.84	2.83	3.8	4.2	0.4	7.8	7.7	7.8	299	300
8	17.0	14.3	63.1	51.9	23.1	18.2	21.9	17.1	4.837	4.898	0.012	0.026	0.021	0.119	9.0	8.1	9.0	8.2	2.75	2.65	2.29	2.33	5.1	6.5	6.2	6.9	8.0	8.1	280	277
14	14.3	7.5	46.9	36.5	19.4	12.6	16.3	11.7	4.415	3.669	0.003	0.043	0.013	0.295	8.1	6.4	8.1	6.7	2.56	2.64	2.05	2.28	9.7	10.5	0.9	7.0	7.9	10.5	260	256
21	21.5	18.1	71.6	61.3	36.4	24.6	32.3	23.1	2.615	1.704	0.035	0.069	0.080	1.113	7.6	5.5	7.7	6.6	1.97	2.11	1.86	2.05	9.9	10.3	18.2	8.1	8.9	8.4	260	217
28	12.2	6.9	77.6	36.7	51.5	15.5	46.5	15.5	0.682	0.002	0.040	0.032	0.145	1.496	6.6	2.9	6.7	4.3	2.25	2.12	1.25	1.88	10.4	11.1	18.4	3.5	9.5	8.1	253	223
Monthly Ave.	16.3	11.5	63.2	44.8	28.6	15.6	25.8	14.7	3.741	3.330	0.019	0.037	0.056	0.614	8.4	6.6	8.5	7.2	2.55	2.53	2.06	2.27	7.8	8.5	8.8	6.7	8.4	8.6	270	255
May 5	6.7	4.4	34.6	25.9	13.2	4.6	11.7	3.8	0.072	0.112	0.033	0.007	0.182	0.432	2.1	1.3	2.3	1.7	0.75	0.74	0.50	0.56	14.5	8.1	17.9	8.1	9.8	9.6	251	246
12	5.6	4.2	33.6	24.1	11.7	3.2	9.2	2.4	0.083	0.114	0.010	0.004	0.025	0.304	1.8	1.3	1.8	1.6	0.68	0.58	0.43	0.75	16.0	15.0	10.6	8.2	9.6	9.5	253	242
Monthly Ave.	6.1	4.3	34.1	25.0	12.5	3.9	10.5	3.1	0.078	0.113	0.022	0.006	0.104	0.368	2.0	1.3	2.1	1.7	0.72	0.66	0.46	0.65	15.3	11.6	14.3	8.2	9.7	9.6	252	244
Filter Run Ave.	17.8	10.0	67.3	38.1	16.2	10.6	12.5	8.7	5.237	6.791	0.021	0.025	0.067	0.383	8.4	7.7	8.5	8.1	2.60	2.56	2.29	2.37	5.0	4.9	6.8	9.4	8.4	8.4	287	299
Filter Run No. 5: 84 consecutive days of operation Hydraulic Loading Rate: 9356 m^3/ha·d (1.0 MGAD) Application Rate: 0.008 m^3/sec (0.29 cfs)																														
June 2	13.8	15.4	36.4	67.8	74.3	39.7	67.6	36.5	0.094	0.099	0.006	0.001	0.084	0.826	8.6	5.8	8.7	6.6	1.51	1.18	0.62	0.59	20.0	20.0	12.0	8.6	9.6	9.6	249	239
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	3.7	2.9	60.1	28.1	8.9	2.9	5.5	2.0	1.180	1.080	0.006	0.062	0.019	0.204	1.9	2.1	1.9	2.3	0.31	1.30	1.06	1.03	17.0	17.0	5.2	7.3	8.6	8.5	210	223
23	17.4	6.0	61.6	40.5	22.7	3.8	19.6	3.0	1.168	0.551	0.016	0.046	0.041	4.000	3.7	1.4	3.7	5.6	1.50	1.31	0.98	1.21	16.2	15.8	10.8	1.4	9.1	8.8	272	263
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monthly Ave.	11.6	8.1	54.2	45.5	35.1	15.5	30.9	13.8	0.810	0.600	0.009	0.020	0.041	1.676	4.7	3.1	4.7	6.7	1.11	1.22	0.88	0.94	17.7	17.6	9.3	5.8	9.1	9.0	244	264
July 7	20.8	13.8	135.5	86.2	64.8	36.4	62.4	35.5	0.112	0.146	0.008	0.002	0.064	2.910	6.9	6.2	7.0	9.1	1.76	2.11	0.51	1.36	23.9	24.0	19.4	6.1	9.5	9.0	247	218
14	14.6	7.5	64.3	51.6	22.4	11.1	18.2	9.0	1.100	0.518	0.016	0.027	0.035	0.700	4.2	2.8	4.2	3.5	1.74	1.80	1.01	1.27	23.0	23.5	8.5	8.0	9.0	9.0	234	231
21	12.7	6.2	74.1	44.7	20.8	6.8	18.3	5.1	1.082	0.545	0.071	0.038	0.033	1.310	4.4	2.3	4.4	3.6	1.63	1.73	0.94	1.24	23.0	22.0	9.7	6.9	9.4	9.0	269	239
28	19.8	7.7	88.9	66.5	35.9	14.3	31.8	12.7	1.267	0.822	0.010	0.035	0.018	1.160	6.5	4.2	6.5	5.6	1.76	1.61	0.95	1.15	23.0	24.0	4.0	5.6	9.2	8.9	203	238
Monthly Ave.	17.0	8.8	90.2	62.3	36.0	17.2	32.5	15.8	0.881	0.480	0.026	0.026	0.039	1.518	5.5	3.9	5.5	5.4	1.73	1.60	0.85	1.26	23.2	23.6	10.4	6.6	9.3	9.0	233	244
August 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	6.2	4.0	50.5	37.6	12.2	2.9	10.0	1.8	1.118	0.492	0.040	0.053	0.026	0.930	5.7	2.7	5.7	3.6	1.47	1.34	0.95	1.15	23.0	22.0	9.8	5.2	8.6	8.2	254	250
18	-	-	54.1	38.1	20.1	4.0	16.9	2.5	1.149	0.537	0.019	0.047	0.013	0.665	3.5	1.8	3.5	2.5	1.53	1.68	1.18	1.63	20.5	20.2	8.7	7.0	8.8	7.4	284	261
25	9.7	8.0	57.8	45.9	20.0	5.6	16.1	4.6	0.935	0.826	0.013	0.098	0.036	0.700	-	-	-	-	1.50	1.63	1.25	1.37	20.0	19.5	-	-	8.8	8.0	263	267
Monthly Ave.	8.0	6.0	54.1	40.5	[illegible]	[illegible]	14.3	3.1	1.030	0.600	0.024	0.066	0.025	0.765	4.6	2.3	4.6	3.1	1.50	1.53	1.13	1.68	21.2	20.6	9.3	6.1	8.7	7.9	267	259
Filter Run Ave.	13.2	7.9	68.8	[illegible]	34.1	[illegible]	29.6	11.5	0.806	[illegible]	0.020	0.036	0.035	1.340	5.0	3.3	5.0	4.6	1.68	1.46	0.94	1.29	21.0	20.9	9.8	6.2	9.1	8.7	247	269

TABLE A-8. COLIFORM REMOVAL PERFORMANCE OF FILTER NO. 1 WITH 0.17 MM EFFECTIVE SIZE SAND

Date	Total Coliform per 100 ml		Fecal Coliform per 100 ml	
	Influent	Effluent	Influent	Effluent
0.17 mm (0.0067 inch) effective size sand filter (Filter No. 1) Filter Run No. 2: 36 consecutive days of operation Hydraulic Loading Rate: 3871.6 $m^3/ha{\cdot}d$(0.4 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)				
Sept. 2, 1975	1.1 (10^2)	40	30	30
4	4.0 (10^2)	90	30	30
9	1.5 (10^2)	140	40	30
16	4.3 (10^3)	2.3 (10^3)	30	30
18	3.9 (10^3)	40	30	30
23	2.3 (10^3)	40	30	30
25	9.3 (10^2)	30	30	30
30	4.3 (10^3)	30	30	30
Oct. 2	7.0 (10^2)	90	30	30
Geometric Mean	5.8 (10^2)	81	31	30
Filter Run No. 3: 166 consecutive days of operation				
Nov. 18	3.3 (10^3)	110	80	20
Jan. 20	2.3 (10^3)	130	1.3 (10^3)	130
22	1.6 (10^5)	350	5.4 (10^4)	350
27	3.3 (10^3)	230	490	22
29	1.7 (10^4)	330	1.7 (10^3)	130
Feb. 3	7.9 (10^3)	330	4.9 (10^3)	170
5	2.4 (10^4)	280	7.9 (10^3)	110
10	9.2 (10^4)	3.5 (10^3)	5.4 (10^4)	2.2 (10^3)
12	9.2 (10^4)	1.6 (10^4)	9.2 (10^4)	5.4 (10^3)
17	7.9 (10^4)	5.4 (10^4)	7.9 (10^4)	3.5 (10^4)
19	1.3 (10^5)	1.7 (10^4)	3.3 (10^4)	7.9 (10^3)
24	2.3 (10^4)	2.3 (10^4)	4.9 (10^4)	7.9 (10^3)
26	7.0 (10^4)	1.3 (10^4)	2.3 (10^4)	1.3 (10^4)

(continued)

TABLE A-8. (CONTINUED)

Date	Total Coliform per 100 ml		Fecal Coliform per 100 ml	
	Influent	Effluent	Influent	Effluent
March 4	4.9 (10^5)	1.1 (10^4)	2.2 (10^5)	1.1 (10^3)
9	3.3 (10^5)	7.9 (10^3)	3.3 (10^5)	3.3 (10^4)
11	3.3 (10^5)	7.9 (10^3)	3.3 (10^5)	2.3 (10^3)
16	-	-	-	-
18	4.9 (10^5)	7.9 (10^3)	1.3 (10^5)	4.9 (10^3)
23	2.2 (10^5)	7.9 (10^3)	1.7 (10^5)	1.7 (10^3)
25	4.9 (10^5)	4.9 (10^3)	7.9 (10^4)	2.3 (10^3)
30	7.9 (10^5)	4.9 (10^4)	1.7 (10^5)	1.1 (10^4)
April 1	4.9 (10^5)	1.4 (10^4)	1.1 (10^5)	7.9 (10^3)
6	4.9 (10^4)	1.1 (10^3)	4.9 (10^4)	200
8	4.9 (10^4)	790	4.9 (10^4)	790
13	2.2 (10^4)	110	2.0 (10^3)	50
22	1.6 (10^4)	70	1.3 (10^3)	20
Geometric Mean	3.0 (10^4)	1.7 (10^3)	2.6 (10^4)	8.4 (10^2)
Filter Run No. 4: 103 consecutive days of operation				
May 8	140	70	2	2
June 22	1.8 (10^3)	240	8	2
24	460	1.3 (10^3)	7	2
July 1	630	410	33	2
8	5.4 (10^3)	130	79	23
13	540	540	170	33
20	490	790	170	5
22	330	330	230	4
29	220	3.5 (10^3)	20	8
Aug. 17	23	5.4 (10^3)	2	2
19	1.7 (10^3)	350	20	2
Geometric Mean	3.0 (10^2)	5.7 (10^2)	24	4

TABLE A-9. COLIFORM REMOVAL PERFORMANCE OF FILTER NO. 3 WITH 0.31 MM EFFECTIVE SIZE SAND.

Date	Total Coliform per 100 ml		Fecal Coliform per 100 ml	
	Influent	Effluent	Influent	Effluent
0.31 mm (0.0122 inch) effective size sand filter (Filter No. 3) Filter Run No. 1: 45 consecutive days of operation Hydraulic Loading Rate: 9354 $m^3/ha \cdot d$(1.0 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)				
July 1	630	4.9 (10^4)	33	790
8	5.4 (10^3)	1.3 (10^4)	79	700
13	540	2.0 (10^3)	170	110
20	490	3.5 (10^4)	170	460
22	330	2.0 (10^3)	230	20
29	220	2.4 (10^3)	20	50
Geometric Mean	6.3 (10^2)	7.7 (10^3)	84	174
Filter Run No. 2: 14 consecutive days of operation Application Rate: 0.008 m^3/sec (0.29 cfs)				
Aug. 17	23	2.4 (10^4)	20	110
19	1.7 (10^3)	5.4 (10^4)	2	130
Geometric Mean	198	3.6 (10^4)	6.3	119

TABLE A-10. COLIFORM REMOVAL PERFORMANCE OF FILTER NO. 2 WITH 0.40 MM EFFECTIVE SIZE SAND.

Date	Total Coliform per 100 ml		Fecal Coliform per 100 ml	
	Influent	Effluent	Influent	Effluent
0.40 mm (0.0158 inch) effective size sand filter (Filter No. 2) Filter Run No. 2: 37 consecutive days of operation Hydraulic Loading Rate: 9354 $m^3/ha \cdot d$(1.0 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)				
Aug. 28	930	9.3 (10^3)	30	90
Sept. 2	110	930	30	30
4	40	230	30	30
9	150	-		
16	4.3 (10^3)	4.3 (10^3)	30	30
18	3.9 (10^3)	110	30	30
23	230	930	30	30
25	930	30	30	30
30	4.3 (10^3)	9.3 (10^3)	30	30
Geometric Mean	6.0 (10^2)	1.8 (10^2)	30	34
Filter Run No. 3: 177 consecutive days of operation				
Nov. 4	220	7.0 (10^3)	20	50
6	20	110	20	20
13	3.3 (10^3)	1.3 (10^3)	790	490
18	3.3 (10^3)	330	80	80
Jan. 20	2.3 (10^3)	7.9 (10^3)	1.3 (10^3)	2.3 (10^3)
22	1.6 (10^5)	340	5.4 (10^4)	340
29	1.7 (10^4)	1.7 (10^3)	130	460
Feb. 3	7.9 (10^3)	230	4.9 (10^3)	80
5	2.4 (10^4)	2.3 (10^3)	7.9 (10^3)	2.3 (10^3)
10	9.2 (10^4)	5.4 (10^4)	5.2 (10^4)	2.2 (10^4)
12	9.2 (10^4)	170	9.2 (10^4)	110
17	7.9 (10^4)	2.4 (10^4)	7.9 (10^4)	2.4 (10^4)
19	7.0 (10^4)	490	3.3 (10^4)	230
24	1.3 (10^5)	230	4.9 (10^4)	130
26	2.3 (10^4)	2.4 (10^4)	2.3 (10^4)	2.4 (10^4)
March 4	4.9 (10^5)	2.4 (10^4)	2.2 (10^5)	2.4 (10^4)
9	4.9 (10^5)	80	3.3 (10^5)	80

(continued)

TABLE A-10. (CONTINUED)

Date	Total Coliform per 100 ml		Fecal Coliform per 100 ml	
	Influent	Effluent	Influent	Effluent
March 11	3.3 (10^5)	2.4 (10^5)	3.3 (10^5)	1.6 (10^5)
23	2.2 (10^5)	2.4 (10^5)	1.7 (10^5)	1.3 (10^5)
30	7.9 (10^5)	1.1 (10^5)	1.7 (10^5)	1.1 (10^5)
April 1	4.9 (10^5)	7.0 (10^4)	1.1 (10^5)	4.6 (10^4)
6	4.9 (10^4)	1.1 (10^4)	4.9 (10^4)	4.9 (10^3)
8	4.9 (10^4)	2.2 (10^4)	4.9 (10^4)	1.4 (10^4)
13	2.2 (10^4)	7.9 (10^3)	2.0 (10^3)	1.3 (10^3)
Geometric Mean	1.6 (10^4)	2.6 (10^3)	1.1 (10^4)	1.8 (10^3)
Filter Run No. 4: 17 consecutive days of operation				
May 4	3.5 (10^3)	3.5 (10^3)	940	240
6	140	170	20	23
Geometric Mean	7.0 (10^2)	7.7 (10^2)	137	74
Filter Run No. 5: 30 non-consecutive days of operation Application Rate: 0.008 m^3/sec (0.29 cfs) (Utilizing primary lagoon effluent)				
May 11	3.5 (10^4)	5.4 (10^3)	1.3 (10^4)	330
13	1.7 (10^5)	7.9 (10^3)	2.3 (10^4)	230
18	4.9 (10^4)	2.4 (10^5)	1.7 (10^4)	2.2 (10^4)
Geometric Mean	6.6 (10^4)	2.2 (10^4)	1.7 (10^4)	1.2 (10^3)

TABLE A-11. COLIFORM REMOVAL PERFORMANCE OF FILTER NO. 3 WITH 0.68 MM EFFECTIVE SIZE SAND

Date	Total Coliform per 100 ml		Fecal Coliform per 100 ml	
	Influent	Effluent	Influent	Effluent
0.68 mm (0.0258 inch) effective size sand filter (Filter No. 3) Filter Run No. 1: 11 consecutive days of operation Hydraulic Loading Rate: 28,062 m^3/ha·d(3.0 MGAD) Application Rate: 0.048 m^3/sec (1.68 cfs)				
Aug. 28	930	7.5 (10^3)	30	0
Geometric Mean	930	7.5 (10^3)	30	0
Filter Run No. 2: 23 consecutive days of operation Hydraulic Loading Rate: 18,708 m^3/ha·d(2.0 MGAD)				
Sept. 9	150	230	40	40
16	4.3 (10^3)	2.3 (10^3)	30	40
18	3.9 (10^3)	1.5 (10^3)	30	30
23	230	390	30	30
25	930	70	30	30
30	4.3 (10^3)	4.3 (10^3)	30	30
Geometric Mean	1.2 (10^3)	6.7 (10^2)	31	33
Filter Run No. 3: 19 consecutive days of operation following 19 days of resting and no scraping				
Nov. 4	220	790	20	20
6	20	3.3 (10^3)	20	20
13	3.3 (10^3)	1.8 (10^3)	790	700
18	3.3 (10^3)	2.8 (10^3)	80	40
Geometric Mean	4.7 (10^2)	4.1 (10^3)	71	58
Filter Run No. 4: 152 consecutive days of operation				
Jan. 20	2.3 (10^3)	80	1.3 (10^3)	50
29	1.7 (10^4)	490	1.7 (10^3)	330
Feb. 3	7.9 (10^3)	20	4.9 (10^3)	20
5	2.4 (10^4)	1.7 (10^4)	7.9 (10^3)	1.4 (10^4)
10	9.2 (10^4)	3.5 (10^4)	5.4 (10^4)	3.5 (10^4)

(continued)

TABLE A-11. (CONTINUED)

Date	Total Coliform per 100 ml		Fecal Coliform per 100 ml	
	Influent	Effluent	Influent	Effluent
Feb. 12	9.2 (10^4)	80	9.2 (10^4)	20
17	7.9 (10^4)	5.4 (10^4)	7.9 (10^4)	3.4 (10^4)
19	7.0 (10^4)	1.4 (10^3)	3.3 (10^4)	600
24	1.3 (10^5)	460	4.9 (10^4)	80
26	2.3 (10^4)	3.5 (10^4)	2.3 (10^4)	3.5 (10^4)
March 23	2.2 (10^5)	1.6 (10^5)	1.7 (10^5)	1.6 (10^5)
30	4.9 (10^5)	7.8 (10^4)	1.7 (10^5)	3.3 (10^4)
April 1	4.9 (10^5)	3.3 (10^4)	1.1 (10^5)	3.3 (10^4)
6	4.9 (10^4)	6.3 (10^4)	4.9 (10^4)	2.2 (10^4)
8	4.9 (10^4)	1.1 (10^4)	4.9 (10^4)	7.0 (10^3)
13	2.2 (10^4)	1.3 (10^4)	2.0 (10^3)	700
22	1.6 (10^4)	800	1.3 (10^3)	200
May 4	3.5 (10^3)	1.4 (10^3)	940	79
6	140	110	20	20
11	-	-	2	5
13	-	-	2	20
Geometric Mean	3.9 (10^4)	3.5 (10^3)	1.3 (10^4)	1.6 (10^3)

TABLE A-12. ALGAE AND ZOOPLANTON COUNTS

Date	Cryptomonas (cells/ml)		Oscillatoria (cells/ml)		Microcystis (cells/ml)		Chlamydomonas (cells/ml)		Pamella (cells/ml)		Navicula (cells/ml)		Euglenoids (cells/ml)		Ankistro-desmus (cells/ml)		Other Algae (cells/ml)		Zooplankton (#/1)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
August 28, 1975																				
Filter No. 6	4,704	78	294	-	1,568	176	-	-	72,128	16,934	2,744	20	-	-	-	-	14,210	-	-	-
Filter No. 3	4,704	274	294	392	1,568	8,283	-	-	72,128	94,080	2,744	98	-	-	-	-	14,210	5,880	-	-
Filter No. 2	4,704	431	294	39	1,568	196	-	39	72,128	921	2,744	706	-	-	-	-	14,210	-	-	-
September 2																				
Filter No. 6	588	-	-	-	8,820	235	-	-	313,600	5,449	-	-	-	-	-	-	392	-	-	-
Filter No. 3	588	294	-	-	8,820	5,488	-	-	313,600	8,232	-	-	-	-	-	-	392	98	-	-
Filter No. 2	588	294	-	-	8,820	4,900	-	-	313,600	35,672	-	-	-	-	-	-	392	-	-	-
September 11																				
Filter No. 3	-	98	-	-	6,860	196	1,960	-	1,281,840	138,768	16,660	1,568					-	-	-	-
Filter No. 2	-	244	-	-	6,860	588	1,960	-	1,281,840	116,816	16,660	686					-	196	-	-
Filter No. 1	-	-	-	-	6,860	274	1,960	-	1,281,840	14,426	16,660	118					-	-	-	-
September 18																				
Filter No. 3	392	549	-	-	11,956	1,607	-	-	11,176	6,742	11,760	1,254	-	-	-	-	247,156	6,542	-	-
Filter No. 2	392	118	-	-	11,956	235	-	-	11,176	5,645	11,760	823	-	-	-	-	247,156	6,116	-	-
Filter No. 1	392	-	-	-	11,956	-	-	-	11,176	4,665	11,760	39	-	-			247,156	432	-	-
September 24																				
Filter No. 3	-	157	-	-	9,212	784	-	-	134,848	19,757	19,600	274	-	-	-	-	1,960	509	-	-
Filter No. 2	-	40	-	-	9,212	706	-	-	134,848	19,130	19,660	157	-	-	-	-	1,960	235	-	-
Filter No. 1	-	-	-	-	9,212	1,176	-	-	134,848	81,536	19,600	-	-	-	-	-	1,960	58	-	-
October 23																				
Filter No. 6	-	-	-	-	1,648	-	-	-	59	-	176	-	-	-	-	-	59	-	76	-
Filter No. 5	-	-	-	-	1,648	78	-	-	59	294	176	-	-	-	-	-	59	215	76	-
Filter No. 2	-	-	-	20	1,648	157	-	-	59	176	176	216	-	-	-	-	59	-	76	-
October 28																				
Filter No. 6	20	-	-	-	39	-	-	-	-	-	-	-	-	-	-	-	39	-	34	-
Filter No. 2	20	39	-	-	39	-	-	-	-	-	-	20	-	-	-	-	39	-	34	-
November 3																				
Filter No. 6	20	-	-	-	-	-	-	39	-	-	-	-	-	-	-	-	-	-	30	-
Filter No. 3	20	20	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	216	30	-
Filter No. 2	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	118	30	-
November 12																				
Filter No. 6	-	20	-	-	20	-	-	-	-	-	-	-	-	-	-	-	20	-	4	-
Filter No. 3	-	78	-	-	20	78	-	-	-	-	-	39	-	-	-	-	20	98	4	-
Filter No. 2	-	59	-	-	20	-	-	-	-	-	-	-	-	-	-	-	20	-	4	-
November 19																				
Filter No. 3	39	-	-	-	98	-	-	20	-	-	-	118	-	-	-	-	-	-	8	-
Filter No. 2	39	59	-	-	98	39	-	39	-	-	-	-	-	-	-	-	-	-	8	-
Filter No. 1	39	20	-	-	98	-	-	20	-	-	-	-	-	-	-	-	-	-	8	-

(continued)

TABLE A-12. (CONTINUED)

Date	Cryptomonas (cells/ml)		Oscillatoria (cells/ml)		Microcystis (cells/ml)		Chlamydomonas (cells/ml)		Pamella (cells/ml)		Navicula (cells/ml)		Euglenoids (cells/ml)		Ankistro-desmus (cells/ml)		Other Algae (cells/ml)		Zooplankton (#/1)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
November 26																				
Filter No. 6	39	39	-	-	98	-	-	-	-	-	-	-	-	-	-	-	40	-	12	-
Filter No. 5	39	59	-	-	98	-	-	-	-	-	-	78	-	-	-	-	40	20	12	-
Filter No. 4	39	98	-	-	98	-	-	-	-	-	-	78	-	-	-	-	40	79	12	-
Filter No. 3	39	78	-	-	98	-	-	20	-	-	-	20	-	-	-	-	40	-	12	-
Filter No. 2	39	98	-	-	98	-	-	-	-	-	-	-	-	-	-	-	40	-	12	-
Filter No. 1	39	20	-	-	98	-	-	-	-	-	-	-	-	-	-	-	40	-	12	-
December 3																				
Filter No. 3	20	137	-	-	20	20	1,117	216	-	-	-	-	-	-	-	-	-	-	18	-
Filter No. 2	20	39	-	-	20	20	1,117	549	-	-	-	-	-	-	-	-	-	20	18	-
Filter No. 1	20	59	-	-	20	20	1,117	137	-	-	-	-	-	-	-	-	-	-	18	-
December 10																				
Filter No. 3	980	392	-	-	1,176	196	10,192	10,584	-	-	392	-	-	-	-	-	-	-	10	-
Filter No. 2	980	588	-	-	1,176	196	10,192	12,348	-	-	392	-	-	-	-	-	-	-	10	-
Filter No. 1	980	157	-	-	1,176	20	10,192	2,783	-	-	392	39	-	-	-	-	-	-	10	-
December 17																				
Filter No. 3	588	588	-	-	392	196	5,480	3,920	-	-	392	-	-	-	-	-	-	-	8	-
Filter No. 2	588	588	-	-	392	392	5,480	4,900	-	-	392	196	-	-	-	-	-	-	8	-
Filter No. 1	588	392	-	-	392	-	5,480	588	-	-	392	-	-	-	-	-	-	-	8	-
December 22																				
Filter No. 3	784	980	-	-	196	392	6,860	5,880	-	-	392	196	-	-	-	-	-	-	10	-
Filter No. 2	784	392	-	-	196	588	6,860	4,508	-	-	392	196	-	-	-	-	-	-	10	-
Filter No. 1	784	588	-	-	196	-	6,860	392	-	-	392	-	-	-	-	-	-	-	10	-
December 29																				
Filter No. 3	1,372	980	-	-	-	-	8,624	6,272	-	-	392	392	-	-	-	-	196	196	8	-
Filter No. 2	1,372	588	-	-	-	-	8,624	2,940	-	-	392	196	-	-	-	-	196	-	8	-
Filter No. 1	1,372	196	-	-	-	196	8,624	784	-	-	392	-	-	-	-	-	196	-	8	-
January 7, 1976																				
Filter No. 3	1,568	980	-	-	-	-	9,604	7,840	-	-	392	588	-	-	196	-	-	-	36	-
Filter No. 2	1,568	588	-	-	-	-	9,604	3,528	-	-	392	196	-	-	196	-	-	-	36	-
Filter No. 1	1,568	196	-	-	-	-	9,604	1,960	-	-	392	196	-	-	196	-	-	196	36	-
January 14																				
Filter No. 3	980	784	-	-	-	-	10,976	9,016	-	-	588	588	-	-	-	-	-	-	24	-
Filter No. 2	980	392	-	-	-	-	10,976	4,704	-	-	588	-	-	-	-	-	-	196	24	-
Filter No. 1	980	196	-	-	-	-	10,976	784	-	-	588	196	-	-	-	-	-	-	24	-
January 21																				
Filter No. 3	1,176	784	-	-	392	196	9,408	6,272	-	-	-	-	-	-	196	-	-	-	32	-
Filter No. 2	1,176	392	-	-	392	196	9,408	3,920	-	-	-	196	-	-	196	-	-	-	32	-
Filter No. 1	1,176	196	-	-	392	-	9,408	1,176	-	-	-	-	-	-	196	-	-	-	32	-

(continued)

TABLE A-12. (CONTINUED)

Date	Cryptomonas (cells/ml)		Oscillatoria (cells/ml)		Microcystis (cells/ml)		Chlamydomonas (cells/ml)		Pamella (cells/ml)		Navicula (cells/ml)		Euglenoids (cells/ml)		Ankistro-desmus (cells/ml)		Other Algae (cells/ml)		Zooplankton (#/1)	
	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.	inf.	eff.
February 18																				
Filter No. 3	-	-	-	-	-	-	1,196	1,921	-	-	-	-	-	-	-	-	-	-	4	-
Filter No. 2	-	-	-	-	-	-	1,196	1,000	-	-	-	-	-	-	-	-	-	-	4	-
Filter No. 1	-	-	-	-	-	-	1,196	294	-	-	-	-	-	-	-	-	-	-	4	-
February 26																				
Filter No. 3	-	-	-	-	-	-	764	510	-	-	-	-	-	-	-	-	-	-	-	-
Filter No. 2	-	-	-	-	-	-	764	353	-	-	-	-	-	-	-	-	-	-	-	-
Filter No. 1	-	-	-	-	-	-	764	216	-	-	-	-	-	-	-	-	-	-	-	-
March 10																				
Filter No. 3	20	20	-	20	60	-	215	294	-	-	-	-	-	-	-	-	-	-	-	-
Filter No. 2	20	-	-	-	60	-	215	59	-	-	-	-	-	-	-	-	-	-	-	-
Filter No. 1	20	-	-	175	60	40	215	-	-	-	-	-	-	-	-	-	-	-	-	-
March 17																				
Filter No. 3	-	-	20	40	-	-	235	175	-	-	-	-	-	-	-	-	20	-	-	-
Filter No. 2	-	-	20	-	-	-	235	40	-	-	-	-	-	-	-	-	20	-	-	-
Filter No. 1	-	-	20	155	-	-	235	40	-	-	-	-	-	-	-	-	20	-	-	-
March 23																				
Filter No. 3	60	-	60	-	-	-	314	196	-	-	-	-	-	-	-	-	-	-	-	-
Filter No. 2	60	-	60	-	-	-	314	80	-	-	-	-	-	-	-	-	-	-	-	-
Filter No. 1	60	-	60	314	-	-	314	60	-	-	-	-	-	-	-	-	-	-	-	-
June 30																				
Filter No. 5	-	-	-	-	451	255	-	-	-	-	-	39	3,881	431	235	118	7,272	3,786	-	-
Filter No. 3	-	-	-	98	451	196	-	-	-	-	-	-	3,881	1,411	235	98	7,272	4,861	-	-
Filter No. 1	-	-	-	-	451	20	-	-	-	-	-	-	3,881	157	235	59	7,272	1,883	-	-
July 14																				
Filter No. 4	-	-	157	78	2,097	1,137	-	-	-	-	-	-	1,392	2,352	-	-	6,506	3,403	340	-
Filter No. 1	-	-	157	-	2,097	79	-	-	-	-	-	-	1,392	1,137	-	117	6,506	1,335	340	-
July 21																				
Filter No. 5	-	-	39	59	1,058	176	-	-	-	-	-	-	4,939	1,274	39	118	7,878	4,940	-	-
Filter No. 3	-	-	39	59	1,058	-	-	-	-	-	-	-	4,939	2,136	39	-	7,878	3,724	-	-
Filter No. 1	-	-	39	20	1,058	-	-	-	-	-	-	-	4,939	1,666	39	-	7,878	79	-	-
August 18																				
Filter No. 5	-	-	60	40	630	39	-	-	-	-	-	-	784	-	79	-	335,199	125,038	420	-
Filter No. 4	-	-	60	98	630	177	-	-	-	-	-	-	784	137	79	40	335,199	186,513	420	-
Filter No. 3	-	-	60	20	630	725	-	-	-	-	-	-	784	372	79	20	335,199	278,905	420	-
Filter No. 1	-	20	60	40	630	39	-	-	-	-	-	39	784	-	79	137	335,199	90,356	420	-

APPENDIX B

COST ESTIMATES

Cost Estimates No. 1
Design Flow: 0.1 MGD
Design Hydraulic Loading Rate: 0.2 MGAD
Locally Available Sand: 0.17 mm effective size filter sand @ 3 feet bed depth
Interest Rate: 7%
Economic Life
- Land--100 years
- Embankment--50 years
- Pumps--10 years
- Sand--20 years
- Gravel--50 years
- Equipment--10 years
- Other--50 years
- Lining And Ramp--20 years

Initial Construction Cost (in place):

Item	Quantity	Unit Cost	Total Cost
Filter media (sand)	4,294 yd^3	7.50	32,205.00
Washed gravel	1,742 yd^3	7.50	13,065.00
Pump (850 gpm)	2	3000.00	6,000.00
Excavation and embankment	13,723	4.50	61,753.50
Building	1	1500.00	1,500.00
Distribution system	2	600.00	1,200.00
Distribution pipe (10 inch)	600 ft.	2.50	1,500.00
PVC pipe (10 inch)	300 ft.	2.50	750.00
Collection pipe (10 inch)	900 ft.	2.50	2,250.00
Ductile iron pipe	100 ft.	10.50	1,050.00
Land	3 acres	1200.00	3,600.00
Bed Lining	61,284 ft^2	0.30	18,385.00
Filter access ramp	26 ft.	36.00	936.00
Initial Maintenance Cost			
Tractor w/front end loader and scraper	1	10,000.00	10,000.00
		Total Cost	$154,194.70

Amortization

Land: (3600) (0.07008) =	252
Pipe: (1500 + 750 + 2250 + 1050) (0.07246) =	402
Sand: (32,205) (0.09439) =	3,040
Gravel: (13,065) (0.07246) =	947
Pumps: (6,000) (0.14238) =	854
Embankment: (61,753.5) (0.07246) =	4,475
Building: (1500) (0.07246) =	109
Dist. Sys.: (1200) (0.07246) =	87
Lining & Ramp: (18,385 + 936) (0.09439) =	1,824
Tractor: (10,000) (0.14238) =	1,424
Total	$13,413

Annual Operating and Maintenance Costs

Maintenance Cost:	1,000/yr.
Manpower Cost: (1/3 man-year @ 10,000 year)	3,333/yr.
Power 15 H.P. @ 2 hrs. of daily operation @ $0.04/kw hr	327/yr.
Sand Washing (amortized at 7%)	300/yr.
Total	$4,960/yr.

Total Annual Cost $18,373

With federal assistance, 75% of construction costs paid by federal government, remaining 25% financed at 7% for 20 years.

(154,194.7) (0.25) (0.09439) =	3,639
O.M.	4,960
	$8,599/yr.

With federal assistance

$$\frac{\text{Total annual cost}}{\text{Total annual flow}} = \frac{\$8{,}599/\text{yr}}{0.1 \text{ MGD } 365 \text{ d/yr}} = \$236/\text{M.G.}$$

$$= \$0.23/1000 \text{ gal.}$$

Without federal assistance

$$\frac{\text{Total annual cost}}{\text{Total annual flow}} = \frac{\$18{,}373\ /\ \text{yr}}{(0.1)\ (365)} = \$503/\text{M.G.}$$

$$= \$0.50/1000 \text{ gal.}$$

Construction Cost Per Acre

$144,194/acre

Cost Estimates No. 2
Design Flow: 1 MGD
Hydraulic Loading Rate: 1 MGAD
Mechanically Sieved Sand: 0.68 mm or 0.40 mm or 0.31 mm effective size filter sand @ 3 feet bed depth
Interest Rate: 7%
Economic Life:

- Land--100 years
- Embankment--50 years
- Pumps--10 years
- Sand--20 years
- Gravel--50 years
- Equipment--10 years
- Other--50 years
- Lining & Ramp: 20 years

Initial Construction Cost (in place):

Item	Quantity	Unit Cost	Total Cost
Filter media (sand)	8,890 yd^3	10.00	88,900.00
Washed gravel	3,855 yd^3	7.50	28,912.50
Pump (5000 gpm)	2	5,000.00	10,000.00
Excavation and Embankment	23,466 yd^3	4.50	105,597.00
Building	1	1,500.00	1,500.00
Distribution System	4	600.00	2,400.00
Distribution Pipe (10 inch)	960 ft.	2.50	2,400.00
Collection Pipe (10 inch)	1,250 ft.	2.50	3,125.00
PVC Pipe (10 inch)	400 ft.	2.50	1,000.00
Ductile Iron Pipe	100 ft.	10.50	1,050.00
Land	5 acres	1,200.00	6,000.00
Bed Lining	111,584 ft^2	0.30	33,475.20
Filter Access Ramp	26 ft.	36.00	936.00
Initial Maintenance Cost			
Tractor w/ front end loader & scraper	1	10,000.00	10,000.00
		Total Cost	$295,295.70

Amortization

Land: (6000) (0.07008) =	420
Pipe: (2400 + 3125 + 1000 + 1050) (0.07246) =	549
Sand: (88,900) (0.09439) =	8,391
Gravel: (28,912.5) (0.07246) =	2,095
Pumps: (10,000) (0.14238) =	1,424
Embankment: (105,597) (0.07246) =	7,652
Building: 1500 (0.07246) =	109
Dist. Sys.: (2400) (0.07246) =	174
Lining & Ramp: (33,475.2 + 936) (0.09439) =	3,248
Tractor: (10,000) (0.14238) =	1,424
Total	$25,486

Annual Operating and Maintenance Costs

Maintenance Cost:	2,000/yr.
Manpower Cost: (1/2 man-year @ $10,000/yr)	5,000/yr.
Power: 50 H.P. @ 33 hrs. of daily operation @ $0.04/kw hr.	1,797/yr.
Sand Washing (amortized at 7%):	500/yr.
Total	$9,297/yr.

Total Annual Cost: $34,783/yr.

With federal assistance, 75% of construction costs paid by federal government, remaining 25% financed at 7% for 20 years.

295,295.70 (0.25) (0.09439) =	6,968/yr.
O.M.	9,297/yr.
	$16,265/yr.

With federal assistance

$$\frac{\text{Total annual cost}}{\text{Total annual flow}} = \frac{\$16,265/\text{yr}}{(1\text{ MGD})\ 365\text{ d/yr}} = \$45/\text{M.G.}$$

$$= \$0.04/1000\text{ gal.}$$

Without federal assistance

$$\frac{\text{Total annual cost}}{\text{Total annual flow}} = \frac{\$34,783/\text{yr}}{(1\text{ MGD})\ (365\text{ d/yr})} = \$95/\text{M.G.}$$

$$= \$0.10/1000\text{ gal.}$$

Construction Cost Per Acre

$285,296/2 Acres = $142,648/Acre

Cost Estimate No. 3
Design Flow: 1 MGD
Design Hydraulic Loading Rate: 0.4 MGAD
Locally Available Sand: 0.17 mm effective size filter sand @ 3 feet bed depth
Interest Rate: 7%
Economic Life:

- Land--100 years
- Embankment--50 years
- Pumps--10 years
- Sand--20 years
- Gravel--50 years
- Equipment--10 years
- Other--50 years
- Lining & Ramp--20 years

Initial Construction Cost (in place):

Item	Quantity	Unit Cost	Total Cost
Filter media (sand)	21,900 yd^3	7.50	164,250.00
Washed gravel	9,348 yd^3	7.50	70,110.00
Pump (5000 gpm)	3	5,000.00	15,000.00
Excavation and Embankment	61,446 yd^3	4.50	276,507.00
Building	1	1,500.00	1,500.00
Distribution System	6	600.00	3,600.00
Distribution Pipe (10 inch)	2,400 ft.	2.50	6,000.00
Collection Pipe (10 inch)	3,600 ft.	2.50	9,000.00
PVC Pipe (10 inch)	2,400 ft.	2.50	6,000.00
Ductile Iron Pipe	100 ft.	10.50	1,050.00
Land	10 acres	1,200.00	12,000.00
Bed Lining	283,608 ft^2	0.30	85,082.40
Filter Access Ramp	78 ft.	36.00	2,808.00

Initial Maintenance Cost

Tractor w/ front end loader & scraper	1	10,000.00	10,000.00
		Total Cost	$662,907.40

Amortization

Land: (12,000) (0.07008) =	841
Pipe: (6000 + 9000 + 6000 + 1050) (0.07246) =	1,598
Sand: (164,250) (0.09439) =	15,504
Gravel: (70,110) (0.07246) =	5,080
Pumps: (15,000) (0.14238) =	2,136
Embankment: 276,507 (0.07246) =	20,036
Building: (1500) (0.07246) =	109
Distribution System: (3600) (0.07246) =	261
Lining and Ramp: (85,082.4 + 2808) (0.09439) =	8,296
Tractor: (10,000) (0.14238) =	1,424
Total	55,285

Annual Operating and Maintenance Costs

Maintenance Cost:	2,000/yr.
Manpower Cost: (1/2 man-year @ 10,000/yr)	5,000/yr.
Power: 50 H.P. @ 1 2/3 hours of daily operation 2 pumps operated daily @ $0.04/kw hr	1,819/yr.
Sand Washing (amortized at 7%):	1,200/yr.
Total	10,019/yr.

Total Annual Cost $65,304

With federal assistance, 75% of construction costs paid by federal government, remaining 25% financed at 7% for 20 years.

662,907.40 (0.25) (0.09439) = $15,643/yr.
O. M. = $10,019/yr.
$28,912/yr.

With federal assistance

$$\frac{\text{Total annual cost}}{\text{Total annual flow}} = \frac{\$25{,}662/\text{yr}}{(1\ \text{MGD})\ 365\ \text{d/yr}} = \$70/\text{M.G.}$$

$$= \$0.07/1000\ \text{gal.}$$

Without federal assistance

$$\frac{\text{Total annual cost}}{\text{Total annual flow}} = \frac{\$65{,}304/\text{yr}}{(1\ \text{MGD})\ 365\ \text{d/yr}} = \$179/\text{M.G.}$$

$$= \$0.18/1000\ \text{gal.}$$

Construction Cost Per Acre

652,907/5 Acres = $13,581/Acre